REPORT

Open Water Flood Hydrology Assessment

Red Deer River and Upper Red Deer River Hazard Studies

Submitted to:

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Executive Summary

Alberta Environment and Parks (AEP) commissioned Golder Associates Ltd. (Golder) in August 2017 to conduct the Upper Red Deer River and Red Deer River Hazard Studies (the studies). The primary purpose of the Upper Red Deer River Study is to assess and identify river and flood hazards along the Red Deer River reach from Coal Camp to Gleniffer Lake and the Bearberry Creek reach from Range Road 62 to its confluence with the Red Deer River in Sundre. The primary purpose of the Red Deer River Hazard Study is to assess and identify river and flood hazards along the Red Deer River reach from Township Road 380 to the Highway 11 Bridge, the Waskasoo Creek reach from the Highway 2A Bridge to its confluence with the Red Deer River, and the Piper Creek reach from Township Road 374 to its confluence with Waskasoo Creek.

The studies are being conducted under the provincial Flood Hazard Identification Program (FHIP), the goals of which include enhancement of public safety and reduction of future flood damages through the identification of river and flood hazards. Project stakeholders include the provincial government, local authorities, and the public. Key municipal stakeholders are Red Deer County, Clearwater County, Mountain View County, the Town of Sundre, the City of Red Deer, Lacombe County, and the Town of Penhold.

The studies include multiple components and deliverables. This report documents the methods and results of the open water hydrology assessment that supports the hydraulic modelling and open water flood mapping. This hydrology assessment includes the following:

- Generation of naturalized daily flow series for the following locations along the Red Deer River: downstream of Dickson Dam, at the City of Red Deer, downstream of the Waskasoo Creek confluence, downstream of the Blindman River confluence, and at Highway 11.
- Generation of regulated daily flow series for the following locations along the Red Deer River: downstream of Dickson Dam, at the City of Red Deer, downstream of the Waskasoo Creek confluence, downstream of the Blindman River confluence, and at Highway 11.
- Development of synthetic flood inflow hydrographs to Gleniffer Lake and flood hydrographs for the Little Red Deer River, Medicine River, Waskasoo Creek, and Blindman River, with hourly time intervals. The hydrographs were completed for 13 return periods, ranging from the 2-year to the 1000-year flood.
- Flow regulation analysis using synthetic flood hydrographs by routing the flood inflow hydrographs through Gleniffer Lake and along the Red Deer River study reach downstream of Dickson Dam.
- Estimation of flood frequencies for various locations along the Red Deer River for natural/naturalized and regulated flow scenarios, including a comparison between regulated flood frequencies determined using two different methodologies and selection of a recommended set of regulated estimates.
- Commentary on the effects of climate change on the flood frequency estimates.

The flood frequency estimates obtained in this study are the most up-to-date for the various locations along the Red Deer River study reach and its tributaries. These estimates provide updated flood hydrology information to be used as input to hydraulic modelling to be conducted in the studies.

This hydrology assessment includes use of the updated June 2013 flood flow data and preliminary estimates of the annual peak flows in 2015 and 2016 for the Red Deer River and its tributaries. The inclusion of these recent flow data increases the sample sizes for the flood frequency analyses and the reliability of resulting flow estimates.

Application of the River Basin Assessment Tools (RBAT) and Water Resources Management Model (WRMM) models, including use of the SSARR channel routing parameters, provides a sound basis to simulate and account for the storage effect of Gleniffer Lake on the flood flows downstream of this reservoir. The resulting natural/naturalized and regulated flood flow series provide good data sets for the flood frequency analyses and for determining appropriate synthetic flood hydrograph peaks.

Tables E1 and E2 summarize the recommended final peak flood frequency estimates for the natural/naturalized and regulated flow scenarios. The 95% upper and lower confidence intervals are provided, where applicable.

Table E.1: Final Flood Frequency Estimates - Natural and Naturalized Flows - Adjusted

WSC Station ID / Node ID	WSC Station Name or Location of Interest	Gross Drainage Area (km²)	Effective Drainage Area (km²)	Flow Type[1]	Distribution	Recommended Instantaneous Flood Flow (m³/s)																							
						1000-yr		750-yr		500-yr		350-yr		200-yr		100-yr		75-yr		50-yr		35-yr		20-yr		10-yr		5-yr		2-yr	
						Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower
RED DEER RIVER																													
05CA009 / Node 200	Red Deer River below Burnt Timber Creek (WSC Station No. 05CA009)	2,246	2,246	N	3P(MLH)	2,370	6,630 / 1,330	2,200	5,910 / 1,260	1,970	4,990 / 1,150	1,780	4,250 / 1,060	1,510	3,300 / 926	1,210	2,390 / 776	1,100	2,080 / 719	954	1,680 / 640	837	1,390 / 574	671	1,020 / 478	493	679 / 367	343	433 / 265	180	210 / 146
Node 100	Red Deer River above Fallentimber Creek	2,616	2,616	N	*Prorated*[3]	2,530	7,720 / 1,550	2,340	6,880 / 1,470	2,080	5,810 / 1,340	1,870	4,950 / 1,230	1,570	3,840 / 1,080	1,250	2,780 / 905	1,130	2,420 / 839	977	1,960 / 745	854	1,620 / 669	681	1,189 / 557	498	791 / 427	345	504 / 309	181	245 / 170
Node 101	Red Deer River below Fallentimber Creek	3,146	3,146	N	*Regionalization*[2]	2,760	9,280 / 1,860	2,530	8,270 / 1,770	2,230	6,990 / 1,610	1,990	5,950 / 1,480	1,660	4,620 / 1,300	1,310	3,340 / 1,090	1,180	2,910 / 1,010	1,010	2,360 / 896	879	1,950 / 805	695	1,430 / 670	504	951 / 514	347	606 / 372	183	295 / 204
Node 102	Red Deer River above Bearberry Creek	3,213	3,213	N	*Regionalization*[2]	2,790	9,480 / 1,900	2,560	8,450 / 1,810	2,260	7,140 / 1,640	2,020	6,080 / 1,510	1,680	4,720 / 1,330	1,330	3,410 / 1,110	1,200	2,970 / 1,030	1,030	2,410 / 915	892	1,990 / 822	706	1,460 / 684	513	971 / 525	353	619 / 380	187	301 / 208
Node 103	Red Deer River below Bearberry Creek	3,451	3,451	N	*Regionalization*[2]	2,920	10,200 / 2,040	2,680	9,080 / 1,940	2,370	7,670 / 1,760	2,120	6,530 / 1,620	1,770	5,070 / 1,430	1,390	3,660 / 1,190	1,260	3,190 / 1,110	1,080	2,590 / 983	941	2,140 / 883	745	1,570 / 735	542	1,040 / 564	374	665 / 408	198	323 / 223
Node 104	Red Deer River above James River	3,586	3,586	N	*Regionalization*[2]	2,990	10,600 / 2,120	2,740	9,440 / 2,020	2,430	7,970 / 1,830	2,170	6,790 / 1,680	1,810	5,270 / 1,490	1,430	3,800 / 1,240	1,290	3,320 / 1,150	1,110	2,690 / 1,020	968	2,220 / 918	767	1,630 / 764	558	1,080 / 586	385	691 / 424	205	336 / 232
Node 105	Red Deer River below James River	4,459	4,459	N	*Regionalization*[2]	3,410	13,200 / 2,640	3,140	11,700 / 2,510	2,790	9,910 / 2,280	2,500	8,440 / 2,090	2,100	6,550 / 1,850	1,670	4,730 / 1,540	1,510	4,130 / 1,430	1,300	3,340 / 1,270	1,140	2,760 / 1,140	905	2,030 / 950	661	1,340 / 729	458	859 / 527	246	418 / 288
05CB911 / Node 201	Red Deer River at Garrington Bridge (AEP Station No. 05CB911)	4,699	4,699	N	*Regionalization*[2,4]	3,500	13,900 / 2,780	3,230	12,300 / 2,650	2,870	10,400 / 2,400	2,580	8,890 / 2,200	2,170	6,900 / 1,950	1,720	4,980 / 1,620	1,560	4,350 / 1,510	1,350	3,520 / 1,340	1,180	2,910 / 1,200	937	2,140 / 1,000	685	1,410 / 768	476	905 / 555	248256	384 / 272
Node 106	Red Deer River above Raven River	4,777	4,777	N	*Regionalization*[2,4]	3,550	14,100 / 2,830	3,280	12,500 / 2,690	2,910	10,600 / 2,440	2,620	9,040 / 2,240	2,200	7,010 / 1,980	1,750	5,060 / 1,650	1,590	4,420 / 1,530	1,370	3,580 / 1,360	1,200	2,960 / 1,220	953	2,180 / 1,020	698	1,430 / 781	484	920 / 564	248261	427 / 293
Node 107	Red Deer River upstream of Gleniffer Lake	5,629	5,583	NZ	3P(MLH)	3,710	7,850 / 2,470	3,430	7,040 / 2,300	3,060	6,020 / 2,090	2,750	5,230 / 1,910	2,320	4,170 / 1,630	1,850	3,050 / 1,340	1,680	2,680 / 1,230	1,450	2,200 / 1,090	1,270	1,850 / 964	1,010	1,380 / 782	733	936 / 583	503	603 / 411	254	293 / 214
Node 108	Red Deer River downstream of Dickson Dam	5,629	5,583	NZ	3P(MLH)	3,710	7,850 / 2,470	3,430	7,040 / 2,300	3,060	6,020 / 2,090	2,750	5,230 / 1,910	2,320	4,170 / 1,630	1,850	3,050 / 1,340	1,680	2,680 / 1,230	1,450	2,200 / 1,090	1,270	1,850 / 964	1,010	1,380 / 782	733	936 / 583	503	603 / 411	254	293 / 214
Node 109	Red Deer River Downstream of Little Red Deer River Confluence	8,207	8,022	NZ	3P(MLH)	4,280	10,900 / 2,950	3,960	9,710 / 2,760	3,540	8,210 / 2,490	3,190	7,050 / 2,280	2,690	5,500 / 1,950	2,150	3,980 / 1,600	1,950	3,450 / 1,460	1,690	2,810 / 1,290	1,480	2,320 / 1,140	1,180	1,690 / 928	858	1,110 / 695	590	704 / 484	299	341 / 243
Node 110	Red Deer River Downstream of Medicine River	10,980	10,696	NZ	3P(MLH)	4,350	7,860 / 2,890	4,050	7,150 / 2,720	3,640	6,250 / 2,500	3,300	5,530 / 2,310	2,820	4,490 / 2,020	2,290	3,410 / 1,690	2,090	3,030 / 1,560	1,820	2,550 / 1,390	1,610	2,190 / 1,250	1,300	1,690 / 1,040	965	1,190 / 794	678	796 / 569	356	412 / 300
Node 111	Red Deer River upstream of Red Deer	11,524	10,966	NZ	3P(MLH)	4,090	7,160 / 2,780	3,800	6,520 / 2,610	3,420	5,700 / 2,400	3,110	5,050 / 2,220	2,660	4,130 / 1,960	2,160	3,170 / 1,630	1,970	2,830 / 1,510	1,720	2,400 / 1,340	1,520	2,050 / 1,200	1,230	1,580 / 989	917	1,120 / 755	647	757 / 545	342	395 / 290
05CC002 / Node 202	Red Deer River at Red Deer (WSC Station No. 05CC002)	11,609	11,052	NZ	3P(MLH)	4,240	7,140 / 2,810	3,940	6,520 / 2,650	3,550	5,710 / 2,440	3,230	5,090 / 2,260	2,760	4,190 / 1,990	2,250	3,230 / 1,670	2,050	2,880 / 1,560	1,790	2,440 / 1,390	1,580	2,090 / 1,250	1,280	1,620 / 1,030	959	1,160 / 788	677	790 / 572	359	416 / 308
Node 112	Red Deer River below Waskasoo Creek	12,096	11,302	NZ	3P(MLH)	4,250	7,170 / 2,810	3,950	6,560 / 2,660	3,560	5,760 / 2,440	3,230	5,110 / 2,260	2,760	4,200 / 2,000	2,240	3,240 / 1,680	2,050	2,880 / 1,560	1,790	2,440 / 1,390	1,580	2,090 / 1,250	1,280	1,620 / 1,030	953	1,150 / 785	672	782 / 568	356	413 / 305
Node 113	Red Deer River above Blindman River	12,096	11,302	NZ	3P(MLH)	4,250	7,170 / 2,810	3,950	6,560 / 2,660	3,560	5,760 / 2,440	3,230	5,110 / 2,260	2,760	4,200 / 2,000	2,240	3,240 / 1,680	2,050	2,880 / 1,560	1,790	2,440 / 1,390	1,580	2,090 / 1,250	1,280	1,620 / 1,030	953	1,150 / 785	672	782 / 568	356	413 / 305

Table E.1: Final Flood Frequency Estimates - Natural and Naturalized Flows - Adjusted

WSC Station ID / Node ID	WSC Station Name or Location of Interest	Gross Drainage Area (km²)	Effective Drainage Area (km²)	Flow Type[1]	Distribution	Recommended Instantaneous Flood Flow (m³/s)																							
						1000-yr		750-yr		500-yr		350-yr		200-yr		100-yr		75-yr		50-yr		35-yr		20-yr		10-yr		5-yr		2-yr	
						Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower
Node 114	Red Deer River below Blindman River	14,010	13,336	NZ	3P(MLH)	4,640	7,790 / 2,890	4,310	7,100 / 2,740	3,880	6,190 / 2,540	3,520	5,490 / 2,360	3,000	4,500 / 2,080	2,430	3,450 / 1,770	2,220	3,070 / 1,640	1,940	2,590 / 1,480	1,710	2,230 / 1,340	1,380	1,720 / 1,120	1,030	1,220 / 855	722	834 / 613	382	450 / 323
Node 115	Red Deer River at Highway 11	14,128	13,454	NZ	3P(MLH)	4,600	7,980 / 2,880	4,270	7,280 / 2,720	3,830	6,350 / 2,510	3,480	5,590 / 2,320	2,960	4,560 / 2,060	2,400	3,480 / 1,740	2,180	3,100 / 1,620	1,900	2,620 / 1,460	1,680	2,220 / 1,320	1,350	1,700 / 1,100	1,000	1,200 / 839	706	815 / 601	374	441 / 316
RED RIVER TRIBUTARIES																													
05CA012 / Node 301	Fallentimber Creek near Sundre (WSC Station No. 05CA012)	489	489	N	LP3(moment)	911	3,030 / 222	820	2,550 / 214	705	2,000 / 201	615	1,610 / 190	492	1,160 / 169	367	763 / 147	323	629 / 138	268	483 / 127	226	382 / 115	169	272 / 96	113	170 / 71.8	70.5	100 / 48	29.5	41.8 / 21.1
05CA011 / Node 302	Bearberry Creek near Sundre (WSC Station No. 05CA011)	238	238	N	EV2	550	1,130 / 117	490	974 / 113	416	796 / 108	360	663 / 104	286	498 / 95	214	351 / 85	189	304 / 80.6	158	248 / 75.4	135	207 / 69.8	104	154 / 61.1	73.3	105 / 49.5	49.2	68.9 / 36.5	23.6	32.9 / 18
05CA002 / Node 303	James River near Sundre (WSC Station No. 05CA002)	821	821	N	LP3(moment)	1,300	3,980 / 430	1,180	3,410 / 413	1,030	2,710 / 384	903	2,210 / 361	735	1,600 / 325	561	1,080 / 277	499	912 / 259	420	709 / 235	358	571 / 211	274	409 / 175	189	262 / 131	122	165 / 88.7	54.9	74 / 41.1
05CB001 / Node 304	Little Red Deer River near the Mouth (WSC Station No. 05CB001)	2,580	2,439	N	LP3(moment)	871	1,830 / 426	810	1,620 / 413	728	1,390 / 390	661	1,190 / 369	563	950 / 336	455	705 / 292	414	619 / 273	360	515 / 247	316	434 / 224	252	334 / 186	184	234 / 138	125	160 / 93.8	58.6	78.5 / 44
05CC007 / Node 305	Medicine River near Eckville (WSC Station No. 05CC007)	1,920	1,857	N	3P(MLH)	503	855 / 328	475	790 / 315	437	708 / 294	405	640 / 277	358	541 / 251	304	436 / 218	282	395 / 205	253	343 / 187	229	301 / 171	193	243 / 147	151	181 / 118	111	133 / 89.9	61.5	75.7 / 49.1
Node 306	Medicine River at the Mouth	2,773	2,674	N	*Prorated*[3]	714	1,230 / 472	673	1,140 / 454	618	1,020 / 423	571	921 / 399	503	779 / 361	424	628 / 314	394	569 / 295	353	494 / 269	318	433 / 246	267	350 / 212	209	261 / 170	156	191 / 129	87.8	109 / 70.7
05CC011 / Node 307	Waskasoo Creek at Red Deer (WSC Station No. 05CC011)	487	250	N	LP3(moment)	107	264 / 39.9	99	231 / 38.5	88.7	192 / 36.7	80.2	161 / 35.1	67.7	122 / 31.9	53.9	87.3 / 27.9	48.7	75.3 / 26.4	41.8	61.7 / 24.2	36.3	51.5 / 21.7	28.3	38.9 / 17.6	19.8	27 / 12.4	12.7	18.3 / 7.91	5.16	8.05 / 3.14
Node 308	Waskasoo Creek above Piper Creek	326	166	N	*Prorated*[3]	72	175 / 26.5	67	154 / 25.6	60.2	128 / 24.4	54.6	107 / 23.3	46.3	81.1 / 21.2	37.1	58 / 18.5	33.5	50.1 / 17.5	28.9	41 / 16.1	25.1	34.2 / 14.4	19.6	25.9 / 11.7	13.7	17.9 / 8.24	8.71	12.2 / 5.26	3.47	5.35 / 2.09
Node 309	Waskasoo Creek below Highway 42	243	142	N	*Prorated*[3]	61.8	149 / 22.6	57.5	131 / 21.9	51.8	109 / 20.8	47	91.3 / 19.9	40	69.2 / 18.1	32.1	49.5 / 15.8	29	42.8 / 14.9	25	35 / 13.7	21.7	29.2 / 12.3	17	22.1 / 9.99	11.9	15.3 / 7.03	7.54	10.4 / 4.49	2.97	4.57 / 1.78
05CC001/ Node 313	Blindman River near Blackfalds	1795.9	1459.1	N	3P(MLH)	739	2100 / 410	685	1870 / 380	612	1590 / 350	553	1370 / 330	468	1050 / 290	375	750 / 240	341	650 / 220	295	530 / 199	258	440 / 180	206	320 / 150	150	210 / 110	102	130 / 80.4	50.4	63.4 / 38.7
WASKASOO CREEK TRIBUTARIES																													
Node 310	Piper Creek above Waskasoo Creek	156	82	N	*Prorated*[3]	36.3	86.3 / 13	33.9	75.5 / 12.6	30.7	62.7 / 12	28	52.6 / 11.5	23.9	39.9 / 10.4	19.3	28.5 / 9.12	17.5	24.6 / 8.63	15.2	20.2 / 7.91	13.2	16.8 / 7.09	10.3	12.7 / 5.75	7.21	8.82 / 4.05	4.55	5.98 / 2.58	1.73	2.63 / 1.03
Node 311	Piper Creek below Highway 595	120	73	N	*Prorated*[3]	32.8	77.8 / 11.7	30.6	68 / 11.3	27.7	56.3 / 10.8	25.3	47.3 / 10.3	21.7	35.9 / 9.33	17.5	25.6 / 8.22	15.9	22.1 / 7.78	13.8	18.2 / 7.11	12	15.1 / 6.36	9.39	11.4 / 5.17	6.55	7.91 / 3.64	4.13	5.38 / 2.32	1.56	2.37 / 0.927
Node 312	Piper Creek below Township Road 374	81	59	N	*Prorated*[3]	26.4	62.3 / 9.37	24.7	54.2 / 9.03	22.4	45 / 8.65	20.5	37.8 / 8.22	17.6	28.7 / 7.46	14.3	20.5 / 6.56	13	17.7 / 6.23	11.2	14.5 / 5.7	9.79	12.1 / 5.09	7.68	9.13 / 4.14	5.36	6.32 / 2.91	3.37	4.3 / 1.85	1.26	1.9 / 0.742

Notes:

1) Flow Type: N: Natural Flows; NZ: Naturalized Flows.
2) Regionalization: Instantaneous flood flows were derived based on regional analysis.
3) Prorated: Instantaneous flood flows were estimated by applying ratio between effective drainage area at the node in interest and node upstream or downstream of the node in interest using regional area power factor.
4) 2-year flood adjusted based on interpolation of values from upstream and downstream nodes.

Table E.2: Final Flood Frequency Estimates - Regulated Flows

WSC Station ID / Node ID	WSC Station Name or Location of Interest	Gross Drainage Area (km²)	Effective Drainage Area (km²)	Flow Type[1]	Recommended Instantaneous Flood Flow (m³/s)																							
					1000-yr		750-yr		500-yr		350-yr		200-yr		100-yr		75-yr		50-yr		35-yr		20-yr		10-yr		5-yr		2-yr	
					Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower
RED DEER RIVER																												
Node 108	Red Deer River downstream of Dickson Dam	5629	5,583	R	3,250	12,908 / 2,591	2,920	11,128 / 2,395	2,470	8,997 / 2,071	2,250	7,763 / 1,924	1,830	5,831 / 1,647	1,310	3,788 / 1,235	1,160	3,225 / 1,116	966	2,524 / 959	811	2,000 / 825	696	898 / 553	512	625 / 420	355	418 / 297	185	218 / 157
Node 109	Red Deer River Downstream of Little Red Deer River Confluence	8207	8,022	R	4,110	8,696 / 2,736	3,700	7,594 / 2,481	3,180	6,256 / 2,172	2,900	5,515 / 2,014	2,390	4,296 / 1,679	1,760	2,902 / 1,275	1,570	2,505 / 1,149	1,330	2,018 / 1,000	1,130	1,646 / 858	676	1,290 / 795	534	898 / 603	402	601 / 427	234	313 / 226
Node 110	Red Deer River Downstream of Medicine River	10980	10,696	R	4,420	9,352 / 2,943	4,000	8,210 / 2,682	3,460	6,807 / 2,363	3,150	5,991 / 2,188	2,620	4,709 / 1,841	1,950	3,215 / 1,412	1,750	2,792 / 1,281	1,480	2,246 / 1,113	1,270	1,850 / 964	768	1,720 / 1,060	619	1,200 / 804	478	801 / 569	290	417 / 301
Node 111	Red Deer River upstream of Red Deer	11524	10,966	R	3,810	9,703 / 2,626	3,500	8,582 / 2,439	3,100	7,190 / 2,181	2,830	6,254 / 2,023	2,390	4,887 / 1,733	1,820	3,369 / 1,354	1,630	2,884 / 1,220	1,390	2,311 / 1,061	1,200	1,881 / 924	720	1,760 / 1,090	586	1,230 / 824	457	821 / 583	282	428 / 309
05CC002. / Node 202	Red Deer River at Red Deer (WSC Station No. 05CC002)	11609	11,052	R	3,810	6,884 / 2,531	3,500	6,179 / 2,351	3,100	5,323 / 2,129	2,830	4,742 / 1,981	2,390	3,805 / 1,712	1,820	2,710 / 1,343	1,630	2,363 / 1,217	1,390	1,948 / 1,062	1,200	1,632 / 932	720	1,770 / 1,100	586	1,240 / 830	457	827 / 588	282	431 / 311
Node 112	Red Deer River below Waskasoo Creek	12096	11,302	R	3,910	6,845 / 2,658	3,590	6,160 / 2,466	3,190	5,317 / 2,239	2,910	4,725 / 2,077	2,460	3,819 / 1,813	1,870	2,744 / 1,411	1,680	2,413 / 1,288	1,430	1,995 / 1,114	1,230	1,659 / 971	721	1,810 / 1,120	587	1,270 / 849	458	846 / 601	283	441 / 318
Node 113	Red Deer River above Blindman River	12096	11,302	R	3,870	6,517 / 2,565	3,570	5,908 / 2,401	3,150	5,067 / 2,165	2,880	4,538 / 2,015	2,440	3,704 / 1,759	1,860	2,670 / 1,381	1,670	2,346 / 1,271	1,430	1,949 / 1,110	1,230	1,627 / 973	721	1,810 / 1,120	587	1,270 / 849	458	846 / 601	283	441 / 318
Node 114	Red Deer River below Blindman River	14010	13,336	R	4,440	7,491 / 2,936	4,130	6,859 / 2,781	3,630	5,873 / 2,488	3,310	5,237 / 2,316	2,810	4,276 / 2,036	2,180	3,153 / 1,635	1,980	2,782 / 1,507	1,720	2,345 / 1,336	1,490	1,971 / 1,179	782	2,140 / 1,320	647	1,500 / 1,000	512	998 / 709	320	520 / 375
Node 115	Red Deer River at Highway 11	14128	13,454	R	4,420	7,457 / 2,922	4,110	6,826 / 2,768	3,610	5,841 / 2,474	3,290	5,205 / 2,302	2,790	4,246 / 2,022	2,180	3,153 / 1,635	1,970	2,768 / 1,499	1,710	2,331 / 1,328	1,490	1,971 / 1,179	770	2,160 / 1,330	640	1,510 / 1,010	508	1,010 / 715	318	525 / 378

Notes:

1) Flow Type: R: Regulated Flows

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1.0 INTRODUCTION

1.1 Study Background

Alberta Environment and Parks (AEP) commissioned Golder Associates Ltd. (Golder) in August 2017 to conduct the Upper Red Deer River and Red Deer River Hazard Studies.

The studies are being conducted under the provincial Flood Hazard Identification Program (FHIP), the goals of which include enhancement of public safety and reduction of future flood damages through the identification of river and flood hazards. Project stakeholders include the Government of Alberta, Red Deer County, Clearwater County, Mountain View County, the Town of Sundre, the City of Red Deer, Lacombe County, and the Town of Penhold, and the public.

The studies include multiple components and deliverables. This report documents the methodology and results of the open water hydrology assessment. The results of the assessment will be used in the hydraulic modelling and open water flood mapping components of the studies.

1.2 Study Objectives

The primary objective of the studies is to identify and assess river and flood hazards along an approximately 126 km reach of the Red Deer River, an approximately 18 km reach of Bearberry Creek, an approximately 33 km reach of Waskasoo Creek, and an approximately 18 km reach of Piper Creek.

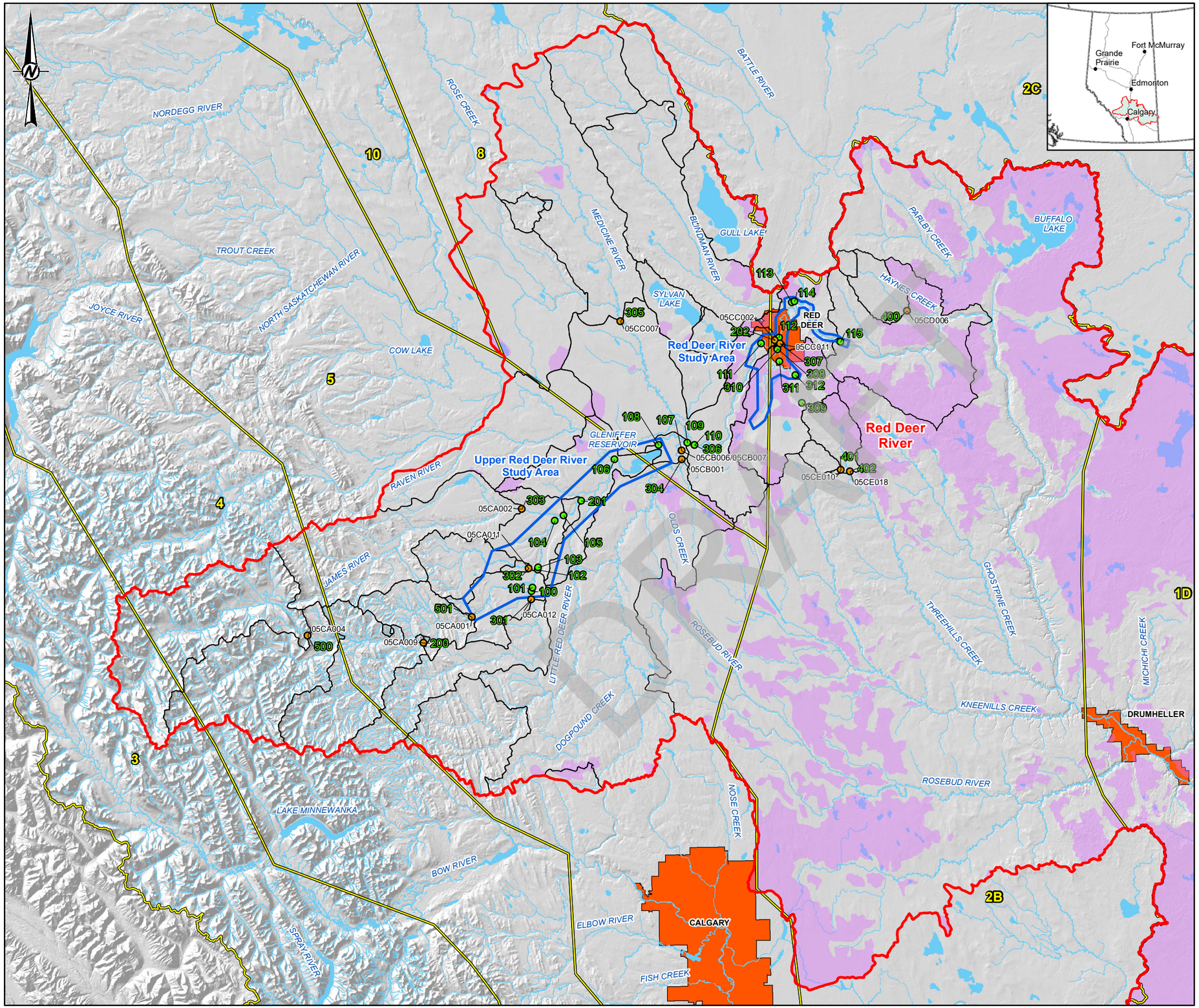
The objective of the open water hydrology assessment component is to generate flood peak discharge estimates for multiple locations along the study reaches of the Red Deer River and Bearberry, Waskasoo and Piper Creeks, including the locations of the Water Survey of Canada (WSC) gauging stations, and the locations upstream and downstream of major tributaries near the City of Red Deer. The hydrology assessment results include estimates of the 2-, 5-, 10-, 20-, 35-, 50-, 75-, 100-, 200-, 350-, 500-, 750-, and 1000-year open water flood peak discharges.

The assessment includes consideration of the preliminary annual maximum instantaneous discharges estimated by WSC for 2015 and 2016. These preliminary estimates are provisional and subject to potential change by WSC.

1.3 Study Area and Reaches

Figure 1.1 shows the open water hydrology study area and the study reaches of the Red Deer River and its tributaries. The major tributaries along the study reach are Fallentimber Creek, Bearberry Creek, James River, Raven River, Little Red Deer River, Medicine River, Waskasoo Creek, Piper Creek, and Blindman River.

Red Deer River and some of its tributaries originate in the Rocky Mountains and traverse the foothills before reaching the Town of Sundre and the City of Red Deer on the edge of the prairies. Red Deer River flows through a mixture of Alpine, Subalpine, Boreal Foothill, and Aspen Parkland eco-regions. Land use in the Red Deer River basin ranges from urban areas, to agricultural in parts of the foothills, and to forest in the remainder of the foothills and in the mountains.



REFERENCE(S)

CITY DATA OBTAINED FROM ALTALIS LTD. HYDROGRAPHY OBTAINED FROM IHS. HYDROMETRIC STATIONS, HYDROLOGIC REGIONS, BASIN AND SUB-BASIN DATA OBTAINED FROM ALBERTA ENVIRONMENT.
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ALBERTA ENVIRONMENT AND PARKS

PROJECT
UPPER RED DEER AND RED DEER RIVER HAZARD STUDIES

TITLE
WATERSHED OF RED DEER RIVER BASIN

CONSULTANT
GOLDER

YYYY-MM-DD	2018-10-11
DESIGNED	G.BIFTU
PREPARED	P.THIEDE
REVIEWED	G.TANG
APPROVED	D.LONG

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1.4 Major Floods

The main weather systems in southern Alberta are cyclonic. They travel from the Pacific Ocean over the cordillera of British Columbia before reaching Alberta. The cordillera is effective at removing moisture from the Pacific air mass, leaving it relatively dry when it reaches the leeward side of the mountain ranges. In addition, Alberta receives cold, dry air masses from the Arctic, and warm, moist air masses from the Gulf of Mexico. In southern Alberta, these air masses may collide, usually between May and July, creating heavy rainfall events.

Past major floods occurred on the Red Deer River in 1915, 1923, 1928, 1929, 1952, 1954, 1990, 1995, 2005 and 2013. The major floods were typically associated with high rainfall or rain-on-snow events during the period May to July. The largest flood peak discharges were typically produced when the snowmelt runoff from the mountains combined with the heavy rainfall runoff from the foothills region of the basin. It is worth noting that the Red Deer River flows downstream of Dickson Dam (and in the Red Deer River Hazard Study area) have been regulated by Gleniffer Lake and Dickson Dam since April 1983.

2.0 DATA SOURCES AND PAST STUDIES

2.1 Data and Information Sources

The hydrology data used in this assessment were assembled from various sources, including the following:

- the historical flow and water level data from the WSC website;
- the preliminary 2015 and 2016 flow data obtained from WSC;
- Gleniffer Lake operation rules obtained from AEP;
- the information of times of travel versus flows provided by AEP for the Red Deer River; and
- the hourly data records of the Gleniffer Lake and tributary rivers and creeks along the study reach obtained from AEP for developing synthetic flood hydrographs.

Table 2.1 provides a summary of the basic hydrologic data and information used to obtain the flood frequency estimates. The information and data details are provided in Appendix A.

Table 2.1: Summary of Data Used for Estimating Flood Frequencies

WSC Number	Node ID	WSC Station Name or Location of Interest	Latitude	Longitude	Gross Drainage Area [km²]	Effective Drainage Area [km²]	Period of Record	Recorded Flow		Naturalized Flow	Regulated Flow
								Length of Record [years]	Type of Recorded Hydrologic Data	Length of Record[1] [years]	Length of Record[2] [years]
RED DEER RIVER											
05CA004	500	Red Deer River above Panther River	51°39'37"	-115°24'38"	941	941	1967 - 2014	48	Flow	n/a	n/a
05CA001	501	Red Deer River near Sundre	51°42'00"	-114°51'20"	2,490	2,490	1950 - 1972	23	Flow	n/a	n/a
05CA009	200	Red Deer River below Burnt Timber Creek	51°38'46"	-115°01'09"	2,246	2,246	1973 - 2016	44	Flow	n/a	n/a
	100	Red Deer River above Fallentimber Creek	51° 45' 14"	-114° 39' 11"	2,616	2,616	n/a	n/a	n/a	n/a	n/a
	101	Red Deer River below Fallentimber Creek	51° 45' 39"	-114° 38' 58"	3,146	3,146	n/a	n/a	n/a	n/a	n/a
	102	Red Deer River above Bearberry Creek	51° 47' 55"	-114° 37' 56"	3,213	3,213	n/a	n/a	n/a	n/a	n/a
	103	Red Deer River below Bearberry Creek	51° 48' 14"	-114° 37' 50"	3,451	3,451	n/a	n/a	n/a	n/a	n/a
	104	Red Deer River above James River	51° 54' 06"	-114° 34' 24"	3,586	3,586	n/a	n/a	n/a	n/a	n/a
	105	Red Deer River below James River	51° 54' 44"	-114° 32' 38"	4,459	4,459	n/a	n/a	n/a	n/a	n/a
05CB003	201	Red Deer River at Garrington Bridge	51° 56' 35"	-114° 28' 59"	4,530	4,699	1971-1972	2	Flow	n/a	n/a
	106	Red Deer River above Raven River	52° 01' 46"	-114° 22' 10"	4,777	4,777	n/a	n/a	n/a	n/a	n/a
05CB006/05CB007	107	Red Deer River upstream of Gleniffer Lake	52°02'47"	-114°08'25"	5,594	5,550	1983 - 2016	34	Flow and Level	n/a	n/a
	108	Red Deer River downstream of Dickson Dam	52°03'30"	-114°13'06"	5,629	5,583	n/a	n/a	n/a	105	105
	109	Red Deer River Downstream of Little Red Deer River Confluence	52° 03' 46"	-114° 07' 12"	8,207	8,022	n/a	n/a	n/a	105	105
	110	Red Deer River Downstream of Medicine River	52° 03' 28"	-114° 05' 46"	10,980	10,696	n/a	n/a	n/a	105	105
	111	Red Deer River upstream of Red Deer	52° 16' 07"	-113° 51' 49"	11,524	10,966	n/a	n/a	n/a	105	105
05CC002	202	Red Deer River at Red Deer	52° 16' 32"	-113° 49' 00"	11,609	11,052	1912 - 1933 and 1935 - 2015	104	Flow	105	105
	112	Red Deer River below Waskasoo Creek	52° 16' 49"	-113° 48' 06"	12,096	11,302	n/a	n/a	n/a	105	105
	113	Red Deer River above Blindman River	52° 21' 14"	-113° 45' 24"	12,096	11,302	n/a	n/a	n/a	105	105
	114	Red Deer River below Blindman River	52° 21' 23"	-113° 44' 52"	14,010	13,336	n/a	n/a	n/a	105	105
	115	Red Deer River at Highway 11	52° 16' 10"	-113° 35' 34"	14,182	13,454	n/a	n/a	n/a	105	105
RED RIVER TRIBUTARIES											
05CA012	301	Fallentimber Creek near Sundre	51°44'12"	-114°39'16"	489	489	1978 - 2016	39	Flow	n/a	n/a
05CA011	302	Bearberry Creek near Sundre	51°48'07"	-114°39'47"	238	238	1978 - 2016	39	Flow	n/a	n/a
05CA002	303	James River near Sundre	51°55'36"	-114°41'07"	821	821	1966 - 2016	51	Flow	n/a	n/a
05CB001	304	Little Red Deer River near the Mouth	52°01'41"	-114°08'25"	2,580	2,439	1960-2016	57	Flow	n/a	n/a
05CC007	305	Medicine River near Eckville	52°19'10"	-114°20'39"	1,920	1,857	1962-2016	55		n/a	n/a
	306	Medicine River at the Mouth	52° 03' 28"	-114° 05' 46"	2,773	2,674	n/a	n/a		n/a	n/a
05CC011	307	Waskasoo Creek at Red Deer	52°16'06"	-113°47'59"	487	250	1984 - 2016	15	Flow	n/a	n/a
	308	Waskasoo Creek above Piper Creek	52° 15' 28"	-113° 48' 36"	326	166	n/a	n/a	n/a	n/a	n/a
	309	Waskasoo Creek below Highway 42	52° 08' 33"	-113° 43' 41"	243	142	n/a	n/a	n/a	n/a	n/a
	310	Piper Creek above Waskasoo Creek	52° 15' 22"	-113° 48' 31"	156	82	n/a	41	n/a	n/a	n/a
	311	Piper Creek below Highway 595	52° 13' 49"	-113° 48' 10"	120	73	n/a	91	n/a	n/a	n/a
	312	Piper Creek below Township Road 374	52° 12' 04"	-113° 44' 56"	81	59	n/a	96	n/a	n/a	n/a
05CC001	313	Blindman River Near Blackfalds	52°21'14.5"	113°47'41.0"	1796	1459	1912 - 2016	62	Flow	n/a	n/a
05CD006	400	Hynes Creek near Hynes	52°19'54"	-113°21'46"	165	165	1978 - 2015	38	Flow	n/a	n/a
05CE010	401	Ray Creek near Insfall	52°00'04"	-113°35'58"	44.4	44.4	1967 - 2014	47	Flow	n/a	n/a
05CE018	402	Threehills Creek below Ray Creek	51°59'50"	-113°34'06"	199	137.6	1971 - 2014	44	Flow	n/a	n/a

Notes:

1) Period of record for naturalized and regulated flows is 1912 to 2016 for a total of 105 years, unless otherwise stated.

2.2 Past Studies

This assessment involved review of background documents, past hydrology studies, and historical flood information, including the following:

- Regional Flood Frequency Analysis for Red Deer River Basin and Adjacent Area (AENV 1992);
- Flood Risk Mapping Study Red Deer River, Dickson Dam to Red Deer including Markerville (AMEC 2007);
- Gleniffer Lake Inflow Study (Golder 2009);
- Oldman River and Red Deer River Basins – 2013 Flood Documentation (Golder 2014a);
- Hydro-Climate Modelling of Alberta South Saskatchewan Regional Planning Area (Golder 2010);
- Routing of the Gleniffer Lake 1:100 Inflow Hydrograph through the Dickson Dam (AENV 2010); and
- McDougal Flats Flood Hazard Study (Golder 2014b).

The review findings were used to establish some of the assumptions used in this assessment, to provide a frame of reference for comparison with the results from this assessment, and to identify the data gaps and apparent discrepancies in the data that may affect their use in subsequent analyses.

3.0 FLOOD FLOW SERIES

3.1 Gauged Locations

The flood flow estimates for the following locations were derived based on the natural flood flow series recorded at the following WSC gauging stations:

- Red Deer River above Panther River (WSC Station No. 05CA004);
- Red Deer River below Burnt Timber Creek (WSC Station No. 05CA009);
- Red Deer River near Sundre (WSC Station No. 05CA001);
- Fallentimber Creek near Sundre (WSC Station No. 05CA012);
- Bearberry Creek near Sundre (WSC Station No. 05CA011);
- James River near Sundre (WSC Station No. 05CA002);
- Little Red Deer River near the Mouth (WSC Station No. 05CB001);
- Medicine River near Eckville (WSC Station No. 05CC007);
- Waskasoo Creek at Red Deer (WSC Station No. 05CC011);
- Blindman River near Blackfalds (WSC Station No. 05CC001);
- Haynes Creek near Hynes (WSC Station No. 05CD006);
- Ray Creek near Insfall (WSC Station No. 05CD007); and
- Threehills Creek below Ray Creek (WSC Station No. 05CE018).

The recorded daily flows for Red Deer River near Sundre (WSC Station No. 05CA001, drainage area of 2,490 km^2) are only available for the period 1950 to 1973. This hydrometric station was moved to an upstream location, and the daily flows have been recorded at Red Deer River below Burnt Timber Creek (WSC Station No. 05CA009, drainage area of 2,246 km^2) since 1973. Similar to the approached used in the McDougal Flats Flood Hazard Study (Golder 2014b), the flow series recorded at these two gauging stations were combined to generate the flow series used to estimate flood flows for Red Deer River below Burnt Timber Creek.

The flood flow series were developed using the natural daily flow series as follows:

- Developed annual maximum daily flood flow series for all locations using the recorded natural flow data series.
- Developed annual maximum instantaneous flood flow series based on the recorded natural flow data series or a relationship established between recorded annual maximum daily and annual maximum instantaneous flood flow series. If the reported annual maximum daily and instantaneous flow values for the same year were not for the same flood event, the annual maximum daily flow values were replaced by the daily flow values for the events corresponding to the annual maximum instantaneous flows.

3.2 Flow Naturalization

Red Deer River flows downstream of Gleniffer Lake have been regulated since 1983 by the operation of Dickson Dam that is located about 50 km upstream of the City of Red Deer. The naturalized daily flow series up to 2016 were developed at Dickson Dam, a number of locations downstream of the major tributary (i.e., Little Red Deer River, Medicine River, Waskasoo Creek, and Blindman River) confluences, the City of Red Deer, and Highway 11 (i.e., locations 100 to 501 shown in Figure 1.1).

3.2.1 Methodology

The flow naturalization was developed following the same method as that used in the Bow, Elbow, Highwood, and Sheep River Hydrology Assessment (Golder 2017). The methodology involved application of the River Basin Assessment Tools (RBAT) model (Optimal Solutions Ltd. 2009) from the Prairie Provinces Water Board (PPWB), the Streamflow Synthesis and Reservoir Regulation (SSARR) channel routing procedures (USACE 1991), and the coefficient values built into the RBAT model and provided by AEP. Details of the Natural Flow Computation software are provided in Appendix B.

The RBAT model was set up for the Red Deer River study reach using a daily calculation time step for the period 1983 to 2016. The model was used for removing the effects of flow regulation by Gleniffer Lake. Missing data for the tributaries were filled using standard techniques (such as linear interpolation or regression using nearby stations) to develop complete series of daily natural flows for all locations.

Most of the major tributaries in the study area have been gauged for the period 1983 to 2016 (see Table 2.1). The recorded natural flows in these tributaries were used for generating naturalized daily flows along the Red Deer River study reach. The Medicine River WSC gauge is not located at its mouth. The ratio calculated based on the effective drainage areas (see Table 3.1) was applied to account for flow contribution from the entire drainage area.

Table 3.1: Ratio of Effective Drainage Areas

Stream Name	Gross Drainage Area at the Mouth [km^2]	Effective Drainage Area at the Mouth [km^2]	Effective Drainage Area at the WSC Gauging Station [km^2]	Ratio
Medicine River	2,773	2,674	1,857	1.44

The relationships of time of travel versus flow obtained from AEP are provided in Table 3.2.

Table 3.2: Travel Times versus Flows

Flow [m^3/s]	Travel Time [hours]			
	Dickson Dam to Little Red Deer River Confluence	Little Red Deer River to the City of Red Deer	City of Red Deer to Blindman River Confluence	Blindman River Confluence to Highway 11(2)
0.00(1)	22.87	134.92	83.31	87.6
0.50	11.68	68.93	45.11	47.4
1	8.75	51.62	34.63	36.4
3	5.53	32.63	22.78	24.0
6	4.14	24.44	17.49	18.4
10	3.35	19.75	14.40	15.1
30	2.12	12.48	9.47	10.0
60	1.58	9.35	7.27	7.7
100	1.58	9.32	5.99	6.3
300	1.55	9.16	3.94	4.1
600	1.52	8.94	3.02	3.2
1,000	1.47	8.66	2.49	2.6
3,000	1.27	7.48	2.30	2.4
6,000	1.05	6.21	2.07	2.2
10,000	0.86	5.07	1.83	1.9
20,000	0.59	3.47	1.42	1.5
30,000	0.45	2.64	1.15	1.2

Notes:

1) Indicates very small discharge

2) Travel time from the Blindman River confluence to Highway 11 is assumed to be one-third of the travel time from the Blindman River confluence to Nevis.

3.2.2 Flow above Gleniffer Lake

The flood flow series for Red Deer River upstream of Gleniffer Lake was derived based on the method outlined below and was included in the development of regional relationships for the upper reach of the Red Deer River.

The natural/naturalized daily flow series for Red Deer River upstream of Gleniffer Lake were derived using RBAT model based on the recorded reservoir levels and outflows (WSC Station Nos. 05CB006 and 05CB007) since 1983 (i.e., the commencement date of the reservoir operation).

The daily natural flows at Gleniffer Lake for the period 1912 to 1983 (i.e., prior to flow regulation) were estimated as follows:

1) Generated naturalized daily flow series for Red Deer River at Red Deer for the period 1983 to 2016 using RBAT model and the recorded flows at WSC Station No. 05CC002 (with an effective drainage area of 11,051 km^2) and removing the effects of Gleniffer Lake storage.

2) Generated daily flow series that represent the naturalized Red Deer River at Red Deer (i.e., flow data generated in Step 1), less the tributary flows from the Little Red Deer River near the Mouth (i.e., natural flow data recorded at WSC Station No. 05CB001) and the Medicine River near Eckville (i.e., natural flow data recorded at WSC Station No. 05CC007). The naturalized daily flow series generated in this step represent runoff from an effective drainage area of about 6,755 km^2 (11,051 km^2 for Red Deer River at Red Deer minus 2,439 km^2 for Little Red Deer River near the Mouth minus 1,857 km^2 for Medicine River near Eckville).

3) A one-day time lag between the Medicine River near Eckville and Red Deer River at Red Deer stations (approximately 120 km) was taken into account to generate the daily flow series.

4) Established relationships for the naturalized daily flows in the Red Deer River above Gleniffer Lake (with an effective drainage area of 5,550 km^2) with other locations as follows:

    a. For each month, correlated naturalized daily flows for the Red Deer River at Gleniffer Lake with the naturalized daily flow series generated in Step 1) (i.e., flow in the Red Deer River at Red Deer with effective drainage area of 11,051 km^2) for the period 1983 to 2015.

    b. For each month, correlated naturalized daily flows for the Red Deer River at Gleniffer Lake with the naturalized daily flow series generated in Step 2) (i.e., the daily flows in the Red Deer at Red Deer less the flows from the Little Red Deer and Medicine Rivers, with effective drainage area of 6,755 km^2) for the period 1983 to 2015.

5) Generated the natural daily flow series for the Red Deer River at Gleniffer Lake using the relationship established in 4(a) for the period from January 1912 to February 1974 and using the relationship established in 4(b) from February 1974 to December 1983. Relationship established in 4(b) was used starting 1974 since significant data is missing for Medicine River near Eckville specially for winter months prior to February 1974.

6) There are data gaps for the periods August 1931 to April 1932 and July 1933 to March 1935 at the stations considered in Step (4) and at all gauging stations within the Red Deer River basin. A relationship between naturalized daily flows in the North Saskatchewan River near Rocky Mountain House and naturalized daily flows in the Red Deer River at Gleniffer Lake were used to fill in the data gaps, which is similar to the approach used in the Bow, Elbow, Highwood, and Sheep River Hydrology Assessment (Golder 2017).

3.2.3 Flow below Gleniffer Lake

The flow naturalization for the various locations along the study reach of the Red Deer River downstream of Gleniffer Lake was conducted using the RBAT model.

Naturalized daily flow series for the Red Deer above Gleniffer Lake for the period 1983 to 2016, the recorded natural flows at the tributaries (i.e., Little Red Deer River, Medicine River, Waskasoo Creek, and Blindman River), and the estimated local runoff to the Red Deer River were used to generate the naturalized flows at the various locations listed in Table 3.3.

Table 3.3: Data and Method used for Generating Natural/Naturalized Daily Flow Series

Location	Method
Red Deer River downstream of the Little Red Deer River confluence	▪ The natural daily flow series for the period 1912 to 1959 was generated based on the recorded daily flows for Red Deer River at Red Deer and the monthly relationship established using the naturalized flows for the period 1983 to 2016. ▪ The natural daily flow series for the period 1960 to 1982 was generated using the natural dally flow series for Red Deer River above Gleniffer Lake and the recorded natural flows in the Little Red River near the Mouth (WSC Station No. 05CB001). ▪ The naturalized daily flow series for the period 1983 to 2016 was generated using the naturalized flows for Red Deer River above Gleniffer Lake and the recorded natural flows in Little Red River near the Mouth (WSC Station No. 05CB001).
Red Deer River downstream of the Medicine River confluence	▪ The natural daily flow series for the period 1912 to 1961 was generated based on the recorded daily flows for Red Deer River at Red Deer and the monthly relationship established using the naturalized flows for the period 1983 to 2016. ▪ The natural daily flow series for the period 1962 to 1982 was generated using the generated data for Red Deer River downstream of the Little Red Deer confluence and the estimated natural flows in Medicine River at the Mouth (based on the recorded flow data at WSC Station No. 05CC007). ▪ The naturalized daily flow series for the period 1983 to 2016 was generated using the generated data for Red Deer River downstream of the Little Red Deer confluence and the estimated natural flows in Medicine River at the Mouth (based on the recorded flow data at WSC Station No. 05CC007).
Red Deer River upstream of the City of Red Deer	▪ The natural daily flow series for the period 1912 to 1982 was generated based on the recorded daily flows for Red Deer River at Red Deer and the monthly relationship established using the naturalized flows for the period 1983 to 2016. ▪ The naturalized daily flow series for the period 1983 to 2016 was generated using the naturalized generated data for Red Deer River below the Medicine River considering the additional drainage area and travel times.
Red Deer River at the City of Red Deer	▪ The naturalized daily flow series was generated using the recorded flows in Red Deer River at Red Deer (WSC Station No. 05CC002) and considering the effects of flow regulation at Dickson Dam.
Red Deer River below Waskasoo Creek confluence	▪ The natural daily flow series for the period 1912 to 1982 was generated based on the recorded daily flows for Red Deer River at Red Deer and the monthly relationship established using the naturalized flows for the period 1983 to 2016. ▪ The naturalized daily flow series for the period 1983 to 2016 was generated using the naturalized flows for Red Deer River at Red Deer and the recorded natural flows in Waskasoo Creek at Red Deer (WSC Station No. 05CC011).
Red Deer River above Blindman River confluence	▪ The natural daily flow series for the period 1912 to 1982 was generated based on the recorded daily flows for Red Deer River at Red Deer and the monthly relationship established using the naturalized flows for the period 1983 to 2016. ▪ The naturalized daily flow series for the period 1983 to 2016 was generated using the naturalized data for Red Deer River below Waskasoo Creek confluence considering travel times.
Red Deer River below Blindman River confluence	▪ The natural daily flow series for the period 1912 to 1915 and 1924 to 1961 was generated based on the recorded daily flows for Red Deer River at Red Deer and the monthly relationship established using the naturalized flows for the period 1983 to 2016. ▪ The natural daily flow series for the periods 1916 to 1923 and 1962 to 1982 was generated using the naturalized flows in Red Deer River above the Blindman River confluence and the recorded natural flows in Blindman River near Blackfalds (WSC Station No. 05CC001). ▪ The naturalized daily flow series for the period 1983 to 2016 was generated using the naturalized flows in Red Deer River above the Blindman River confluence and the recorded natural flows in Blindman River near Blackfalds (WSC Station No. 05CC001).
Red Deer River at Highway 11	▪ The natural daily flow series for the period 1912 to 1982 was generated based on the recorded daily flows for Red Deer River at Red Deer and the monthly relationship established using the naturalized flows for the period 1983 to 2016. ▪ The naturalized daily flow series for the period 1983 to 2016 was generated using the generated data for Red Deer River below the Blindman River confluence considering the additional drainage area and travel times.

The daily natural flows for the various locations along the Red Deer River reach downstream of Dickson Dam for the period 1912 to 1983 (i.e., prior to flow regulation), were estimated using the following method:

1) For each month, correlated naturalized daily flows for Red Deer River at Red Deer with the naturalized daily flow series generated at each location for the period 1983 to 2016.

2) Generated the natural daily flow series at each location for the period 1912 to 1982 using the relationship established in Step 1) and recorded flow data for the tributaries prior to 1982 as listed in Table 3.3.

3.3 Annual Maximum Instantaneous Flow Series

The annual maximum instantaneous flow series for Red Deer River and its tributaries were derived using the following method:

- For the locations with no upstream flow regulation (i.e., the various locations along Red Deer River upstream of Gleniffer Lake and all tributaries of Red Deer River), the relationships between the recorded annual maximum daily and instantaneous flows for the same flood events, were established and used to fill any data gaps to generate the annual maximum instantaneous flow series for the periods of records.
- Along the Red Deer River reach downstream of Dickson Dam, the annual maximum daily flow series were converted to the annual maximum instantaneous flow series using the relationships established for Red Deer River at Red Deer based on the natural flow series (i.e., recorded flow data before 1983) and the regulated flow series (i.e., recorded flow data after 1983), were used for all of the locations along Red Deer River between Dickson Dam and Highway 11. The relationships established for Red Deer River at Red Deer indicate that the effect of flow regulation on the relationship is relatively small. The relationships before and after the flow regulation are very similar.

Appendix A presents the relationship established between the annual maximum daily and instantaneous flows for Red Deer River and its tributaries. Each relationship was evaluated and selected based on the statistical best-fit and professional judgement. Appendix A also presents the plots of the recorded and estimated annual maximum instantaneous flow series.

4.0 FLOOD FREQUENCY ANALYSIS

4.1 Statistical Tests

4.1.1 Methods

Prior to fitting the appropriate frequency distribution to the flood flow data, a number of statistical tests were performed to determine the quality of the flood flow data series. A Golder software tool similar to Environment Canada's Consolidated Frequency Analysis (CFA), but with enhanced methodology, was used for flood frequency analyses as well as statistical tests for independence (not serially correlated), trend, randomness, and homogeneity. The software tool includes modern boot strapping and estimation of confidence intervals.

The following probability distributions were analyzed with select parameter estimation methods (i.e., method of moments [moment], maximum likelihood estimation [MLH], and Method of L-moments [MLM]):

- Three-parameter Log Normal (moment and MLH);
- Generalized Extreme Value Distribution that includes Extreme Value 1, 2, and 3 distributions (MLM);
- Log Pearson Type III (LP3, moment and MLH); and
- Weibull (moment).

Numerical goodness-of-fit test was performed using the non-parametric Anderson-Darling test (Stephens 1974).

Frequency analyses of the annual maximum instantaneous flow series (for the natural and naturalized as well as regulated flood flow series) were conducted for estimating the flood peak discharges of various return periods (i.e., 2-, 5-, 10-, 20-, 35-, 50-, 75-, 100-, 200-, 350-, 500-, 750-, and 1000-year floods). Fitting statistical probability distributions followed the standard approach. While this approach produced reasonable and appropriate results, accurate flood frequency estimates are influenced by sufficient data sample size. Estimates of return periods greater than 100 years based on a relatively short period of record are expected to have a high level of uncertainty. The level of uncertainty is represented by the upper and lower 95% confidence intervals. Therefore, extra care should be applied for estimates that have very large confidence intervals.

4.1.2 Results

Tables A-1 and A-2 in Appendix A provide the results of statistical tests on the recorded, naturalized, and regulated annual maximum instantaneous flow series at various locations along the study reach of Red Deer River and its tributaries. The results show that most of the annual maximum instantaneous flow series are independent, random, homogeneous, and do not display any significant trends. The results are highlighted and discussed below:

- The naturalized annual maximum instantaneous flood series for Red Deer River downstream of the confluence with Little Red Deer River, display non-randomness at the 5% level of significance but the data are random at the 1% level of significance for naturalized flood flow series.
- The regulated annual maximum instantaneous flood series for all locations of Red Deer River downstream of Dickson Dam, display non-independence at the 5% level of significance but the data are independent at the 1% level of significance for naturalized flood flow series.
- Non-independence and non-randomness of the flow data might have been caused by flow regulations (i.e., regulated changes affecting the statistical properties of the data through time). In reality, obtaining perfectly independent and random data is almost impossible, because changes such as reservoir operations affecting the flows. Notwithstanding the non-independence and non-randomness of the instantaneous annual flow series, the entire series were considered appropriate for the flood frequency analysis.
- The annual maximum instantaneous natural flow series for Little Red Deer River at the Mouth display non-independence and non-homogeneous at the 5% level of significance and non-randomness at the 1% and 5% level of significance.

4.2 Natural and Naturalized Flood Flow Scenario

4.2.1 Single Station Analysis

4.2.1.1 Red Deer River

Frequency analyses of the annual maximum instantaneous flow series (which include the preliminary estimates of the 2015 and 2016 flood flows by WSC) for the natural/naturalized flood flows at various locations along the study reach of Red Deer River, were conducted for estimating the flood peak discharge of various return periods (i.e., 2-, 5-, 10-, 20-, 35-, 50-, 75-, 100-, 200-, 350-, 500-, 750-, and 1000-year floods). Table 4.1 summarizes the resulting flood frequency estimates and the upper and lower 95% confidence intervals.

Appendix C provides the annual maximum instantaneous flow series used for the flood frequency analyses, the various frequency distributions, and the best distribution fit with 95% confidence intervals.

The results show that almost all the annual maximum instantaneous flow series are contained within the 95% confidence curves.

For Red Deer River below Burnt Timber Creek, the flood frequency estimates based on the three parameter Log normal distribution using maximum likelihood estimate are recommended, although the goodness-of-fit based on non-parametric Anderson-Darling test indicates selection of Log Pearson Type III using maximum likelihood estimate. Use of the Log Pearson Type III method results in over estimation of flood magnitudes for return periods higher than 10 years.

For Red Deer River below Blindman River and Red Deer River at Highway 11, the flood frequency estimates based on the three parameter Log normal distribution using maximum likelihood estimate are recommended, although the goodness-of-fit based on non-parametric Anderson-Darling test indicates selection of Log Pearson Type III using maximum likelihood estimate for Red Deer River below Blindman River and Weibull for Red Deer River at Highway 11. Use of the Log Pearson Type III and Weibull methods result in under estimation of flood magnitudes for return periods higher than 10 years.

The results indicate that the estimated flood peak discharges along the Red Deer River reaches between Medicine River and the City of Red Deer, and between the Blindman River confluence and Highway 11, decrease due to flood attenuation.

Table 4.1: Flood Frequency Estimates – Natural/Naturalized Flows- Adjusted

WSC Station ID / Node ID	WSC Station Name or Location of Interest	Gross Drainage Area (km²)	Effective Drainage Area (km²)	Flow Type[1]	Distribution	Recommended Instantaneous Flood Flows\ (m³/s)																							
						1000-yr		750-yr		500-yr		350-yr		200-yr		100-yr		75-yr		50-yr		35-yr		20-yr		10-yr		5-yr		2-yr	
						Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower
RED DEER RIVER																													
05CA009 / Node 200	Red Deer River below Burnt Timber Creek (WSC Station No. 05CA009)	2,246	2,246	N	3P(MLH)	2,370	6,630 / 1,330	2,200	5,910 / 1,260	1,970	4,990 / 1,150	1,780	4,250 / 1,060	1,510	3,300 / 926	1,210	2,390 / 776	1,100	2,080 / 719	954	1,680 / 640	837	1,390 / 574	671	1,020 / 478	493	679 / 367	343	433 / 265	180	210 / 146
Node 100	Red Deer River above Fallentimber Creek	2,616	2,616	N	*Prorated*[3]	2,530	7,720 / 1,550	2,340	6,880 / 1,470	2,080	5,810 / 1,340	1,870	4,950 / 1,230	1,570	3,840 / 1,080	1,250	2,780 / 905	1,130	2,420 / 839	977	1,960 / 745	854	1,620 / 669	681	1,189 / 557	498	791 / 427	345	504 / 309	181	245 / 170
Node 101	Red Deer River below Fallentimber Creek	3,146	3,146	N	*regionalization*[2]	2,760	9,280 / 1,860	2,530	8,270 / 1,770	2,230	6,990 / 1,610	1,990	5,950 / 1,480	1,660	4,620 / 1,300	1,310	3,340 / 1,090	1,180	2,910 / 1,010	1,010	2,360 / 896	879	1,950 / 805	695	1,430 / 670	504	951 / 514	347	606 / 372	183	295 / 204
Node 102	Red Deer River above Bearberry Creek	3,213	3,213	N	*regionalization*[2]	2,790	9,480 / 1,900	2,560	8,450 / 1,810	2,260	7,140 / 1,640	2,020	6,080 / 1,510	1,680	4,720 / 1,330	1,330	3,410 / 1,110	1,200	2,970 / 1,030	1,030	2,410 / 915	892	1,990 / 822	706	1,460 / 684	513	971 / 525	353	619 / 380	187	301 / 208
Node 103	Red Deer River below Bearberry Creek	3,451	3,451	N	*regionalization*[2]	2,920	10,200 / 2,040	2,680	9,080 / 1,940	2,370	7,670 / 1,760	2,120	6,530 / 1,620	1,770	5,070 / 1,430	1,390	3,660 / 1,190	1,260	3,190 / 1,110	1,080	2,590 / 983	941	2,140 / 883	745	1,570 / 735	542	1,040 / 564	374	665 / 408	198	323 / 223
Node 104	Red Deer River above James River	3,586	3,586	N	*regionalization*[2]	2,990	10,600 / 2,120	2,740	9,440 / 2,020	2,430	7,970 / 1,830	2,170	6,790 / 1,680	1,810	5,270 / 1,490	1,430	3,800 / 1,240	1,290	3,320 / 1,150	1,110	2,690 / 1,020	968	2,220 / 918	767	1,630 / 764	558	1,080 / 586	385	691 / 424	205	336 / 232
Node 105	Red Deer River below James River	4,459	4,459	N	*regionalization*[2]	3,410	13,200 / 2,640	3,140	11,700 / 2,510	2,790	9,910 / 2,280	2,500	8,440 / 2,090	2,100	6,550 / 1,850	1,670	4,730 / 1,540	1,510	4,130 / 1,430	1,300	3,340 / 1,270	1,140	2,760 / 1,140	905	2,030 / 950	661	1,340 / 729	458	859 / 527	246	418 / 288
05CB911 / Node 201	Red Deer River at Garrington Bridge (AEP Station No. 05CB911)	4,699	4,699	N	*regionalization*[2,4]	3,500	13,900 / 2,780	3,230	12,300 / 2,650	2,870	10,400 / 2,400	2,580	8,890 / 2,200	2,170	6,900 / 1,950	1,720	4,980 / 1,620	1,560	4,350 / 1,510	1,350	3,520 / 1,340	1,180	2,910 / 1,200	937	2,140 / 1,000	685	1,410 / 768	476	905 / 555	248	384 / 272
Node 106	Red Deer River above Raven River	4,777	4,777	N	*regionalization*[2,4]	3,550	14,100 / 2,830	3,280	12,500 / 2,690	2,910	10,600 / 2,440	2,620	9,040 / 2,240	2,200	7,010 / 1,980	1,750	5,060 / 1,650	1,590	4,420 / 1,530	1,370	3,580 / 1,360	1,200	2,960 / 1,220	953	2,180 / 1,020	698	1,430 / 781	484	920 / 564	248	427 / 293
Node 107	Red Deer River upstream of Gleniffer Lake	5,629	5,583	NZ	3P(MLH)	3,710	7,850 / 2,470	3,430	7,040 / 2,300	3,060	6,020 / 2,090	2,750	5,230 / 1,910	2,320	4,170 / 1,630	1,850	3,050 / 1,340	1,680	2,680 / 1,230	1,450	2,200 / 1,090	1,270	1,850 / 964	1,010	1,380 / 782	733	936 / 583	503	603 / 411	254	293 / 214
Node 108	Red Deer River downstream of Dickson Dam	5,629	5,583	NZ	3P(MLH)	3,710	7,850 / 2,470	3,430	7,040 / 2,300	3,060	6,020 / 2,090	2,750	5,230 / 1,910	2,320	4,170 / 1,630	1,850	3,050 / 1,340	1,680	2,680 / 1,230	1,450	2,200 / 1,090	1,270	1,850 / 964	1,010	1,380 / 782	733	936 / 583	503	603 / 411	254	293 / 214
Node 109	Red Deer River Downstream of Little Red Deer River Confluence	8,207	8,022	NZ	3P(MLH)	4,280	10,900 / 2,950	3,960	9,710 / 2,760	3,540	8,210 / 2,490	3,190	7,050 / 2,280	2,690	5,500 / 1,950	2,150	3,980 / 1,600	1,950	3,450 / 1,460	1,690	2,810 / 1,290	1,480	2,320 / 1,140	1,180	1,690 / 928	858	1,110 / 695	590	704 / 484	299	341 / 243
Node 110	Red Deer River Downstream of Medicine River	10,980	10,696	NZ	3P(MLH)	4,350	7,860 / 2,890	4,050	7,150 / 2,720	3,640	6,250 / 2,500	3,300	5,530 / 2,310	2,820	4,490 / 2,020	2,290	3,410 / 1,690	2,090	3,030 / 1,560	1,820	2,550 / 1,390	1,610	2,190 / 1,250	1,300	1,690 / 1,040	965	1,190 / 794	678	796 / 569	356	412 / 300
Node 111	Red Deer River upstream of Red Deer	11,524	10,966	NZ	3P(MLH)	4,090	7,160 / 2,780	3,800	6,520 / 2,610	3,420	5,700 / 2,400	3,110	5,050 / 2,220	2,660	4,130 / 1,960	2,160	3,170 / 1,630	1,970	2,830 / 1,510	1,720	2,400 / 1,340	1,520	2,050 / 1,200	1,230	1,580 / 989	917	1,120 / 755	647	757 / 545	342	395 / 290
05CC002 / Node 202	Red Deer River at Red Deer (WSC Station No. 05CC002)	11,609	11,052	NZ	3P(MLH)	4,240	7,140 / 2,810	3,940	6,520 / 2,650	3,550	5,710 / 2,440	3,230	5,090 / 2,260	2,760	4,190 / 1,990	2,250	3,230 / 1,670	2,050	2,880 / 1,560	1,790	2,440 / 1,390	1,580	2,090 / 1,250	1,280	1,620 / 1,030	959	1,160 / 788	677	790 / 572	359	416 / 308

Table 4.1: Flood Frequency Estimates – Natural/Naturalized Flows- Adjusted

WSC Station ID / Node ID	WSC Station Name or Location of Interest	Gross Drainage Area (km²)	Effective Drainage Area (km²)	Flow Type[1]	Distribution	Recommended Instantaneous Flood Flows\ (m³/s)																							
						1000-yr		750-yr		500-yr		350-yr		200-yr		100-yr		75-yr		50-yr		35-yr		20-yr		10-yr		5-yr		2-yr	
						Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower
Node 112	Red Deer River below Waskasoo Creek	12,096	11,302	NZ	3P(MLH)	4,250	7,170 / 2,810	3,950	6,560 / 2,660	3,560	5,760 / 2,440	3,230	5,110 / 2,260	2,760	4,200 / 2,000	2,240	3,240 / 1,680	2,050	2,880 / 1,560	1,790	2,440 / 1,390	1,580	2,090 / 1,250	1,280	1,620 / 1,030	953	1,150 / 785	672	782 / 568	356	413 / 305
Node 113	Red Deer River above Blindman River	12,096	11,302	NZ	3P(MLH)	4,250	7,170 / 2,810	3,950	6,560 / 2,660	3,560	5,760 / 2,440	3,230	5,110 / 2,260	2,760	4,200 / 2,000	2,240	3,240 / 1,680	2,050	2,880 / 1,560	1,790	2,440 / 1,390	1,580	2,090 / 1,250	1,280	1,620 / 1,030	953	1,150 / 785	672	782 / 568	356	413 / 305
Node 114	Red Deer River below Blindman River	14,010	13,336	NZ	3P(MLH)	4,640	7,790 / 2,890	4,310	7,100 / 2,740	3,880	6,190 / 2,540	3,520	5,490 / 2,360	3,000	4,500 / 2,080	2,430	3,450 / 1,770	2,220	3,070 / 1,640	1,940	2,590 / 1,480	1,710	2,230 / 1,340	1,380	1,720 / 1,120	1,030	1,220 / 855	722	834 / 613	382	450 / 323
Node 115	Red Deer River at Highway 11	14,128	13,454	NZ	3P(MLH)	4,600	7,980 / 2,880	4,270	7,280 / 2,720	3,830	6,350 / 2,510	3,480	5,590 / 2,320	2,960	4,560 / 2,060	2,400	3,480 / 1,740	2,180	3,100 / 1,620	1,900	2,620 / 1,460	1,680	2,220 / 1,320	1,350	1,700 / 1,100	1,000	1,200 / 839	706	815 / 601	374	441 / 316
RED RIVER TRIBUTARIES																													
05CA012 / Node 301	Fallentimber Creek near Sundre (WSC Station No. 05CA012)	489	489	N	LP3(moment)	911	3,030 / 222	820	2,550 / 214	705	2,000 / 201	615	1,610 / 190	492	1,160 / 169	367	763 / 147	323	629 / 138	268	483 / 127	226	382 / 115	169	272 / 96	113	170 / 71.8	70.5	100 / 48	29.5	41.8 / 21.1
05CA011 / Node 302	Bearberry Creek near Sundre (WSC Station No. 05CA011)	238	238	N	EV2	550	1,130 / 117	490	974 / 113	416	796 / 108	360	663 / 104	286	498 / 95	214	351 / 85	189	304 / 80.6	158	248 / 75.4	135	207 / 69.8	104	154 / 61.1	73.3	105 / 49.5	49.2	68.9 / 36.5	23.6	32.9 / 18
05CA002 / Node 303	James River near Sundre (WSC Station No. 05CA002)	821	821	N	LP3(moment)	1,300	3,980 / 430	1,180	3,410 / 413	1,030	2,710 / 384	903	2,210 / 361	735	1,600 / 325	561	1,080 / 277	499	912 / 259	420	709 / 235	358	571 / 211	274	409 / 175	189	262 / 131	122	165 / 88.7	54.9	74 / 41.1
05CB001 / Node 304	Little Red Deer River near the Mouth (WSC Station No. 05CB001)	2,580	2,439	N	LP3(moment)	871	1,830 / 426	810	1,620 / 413	728	1,390 / 390	661	1,190 / 369	563	950 / 336	455	705 / 292	414	619 / 273	360	515 / 247	316	434 / 224	252	334 / 186	184	234 / 138	125	160 / 93.8	58.6	78.5 / 44
05CC007 / Node 305	Medicine River near Eckville (WSC Station No. 05CC007)	1,920	1,857	N	3P(MLH)	503	855 / 328	475	790 / 315	437	708 / 294	405	640 / 277	358	541 / 251	304	436 / 218	282	395 / 205	253	343 / 187	229	301 / 171	193	243 / 147	151	181 / 118	111	133 / 89.9	61.5	75.7 / 49.1
Node 306	Medicine River at the Mouth	2,773	2,674	N	*Prorated*[3]	714	1,230 / 472	673	1,140 / 454	618	1,020 / 423	571	921 / 399	503	779 / 361	424	628 / 314	394	569 / 295	353	494 / 269	318	433 / 246	267	350 / 212	209	261 / 170	156	191 / 129	87.8	109 / 70.7
05CC011 / Node 307	Waskasoo Creek at Red Deer (WSC Station No. 05CC011)	487	250	N	LP3(moment)	107	264 / 39.9	99	231 / 38.5	88.7	192 / 36.7	80.2	161 / 35.1	67.7	122 / 31.9	53.9	87.3 / 27.9	48.7	75.3 / 26.4	41.8	61.7 / 24.2	36.3	51.5 / 21.7	28.3	38.9 / 17.6	19.8	27 / 12.4	12.7	18.3 / 7.91	5.16	8.05 / 3.14
Node 308	Waskasoo Creek above Piper Creek	326	166	N	*Prorated*[3]	72	175 / 26.5	67	154 / 25.6	60.2	128 / 24.4	54.6	107 / 23.3	46.3	81.1 / 21.2	37.1	58 / 18.5	33.5	50.1 / 17.5	28.9	41 / 16.1	25.1	34.2 / 14.4	19.6	25.9 / 11.7	13.7	17.9 / 8.24	8.71	12.2 / 5.26	3.47	5.35 / 2.09
Node 309	Waskasoo Creek below Highway 42	243	142	N	*Prorated*[3]	61.8	149 / 22.6	57.5	131 / 21.9	51.8	109 / 20.8	47	91.3 / 19.9	40	69.2 / 18.1	32.1	49.5 / 15.8	29	42.8 / 14.9	25	35 / 13.7	21.7	29.2 / 12.3	17	22.1 / 9.99	11.9	15.3 / 7.03	7.54	10.4 / 4.49	2.97	4.57 / 1.78
05CC001/ Node 313	Blindman River near Blackfalds	1795.9	1459.1	N	3P(MLH)	739	2100 / 410	685	1870 / 380	612	1590 / 350	553	1370 / 330	468	1050 / 290	375	750 / 240	341	650 / 220	295	530 / 199	258	440 / 180	206	320 / 150	150	210 / 110	102	130 / 80.4	50.4	63.4 / 38.7

Table 4.1: Flood Frequency Estimates – Natural/Naturalized Flows- Adjusted

WSC Station ID / Node ID	WSC Station Name or Location of Interest	Gross Drainage Area (km²)	Effective Drainage Area (km²)	Flow Type[1]	Distribution	Recommended Instantaneous Flood Flows\ (m³/s)																							
						1000-yr		750-yr		500-yr		350-yr		200-yr		100-yr		75-yr		50-yr		35-yr		20-yr		10-yr		5-yr		2-yr	
						Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower
WASKASOO CREEK TRIBUTARIES																													
Node 310	Piper Creek above Waskasoo Creek	156	82	N	*Prorated*[3]	36.3	86.3 / 13	33.9	75.5 / 12.6	30.7	62.7 / 12	28	52.6 / 11.5	23.9	39.9 / 10.4	19.3	28.5 / 9.12	17.5	24.6 / 8.63	15.2	20.2 / 7.91	13.2	16.8 / 7.09	10.3	12.7 / 5.75	7.21	8.82 / 4.05	4.55	5.98 / 2.58	1.73	2.63 / 1.03
Node 311	Piper Creek below Highway 595	120	73	N	*Prorated*[3]	32.8	77.8 / 11.7	30.6	68 / 11.3	27.7	56.3 / 10.8	25.3	47.3 / 10.3	21.7	35.9 / 9.33	17.5	25.6 / 8.22	15.9	22.1 / 7.78	13.8	18.2 / 7.11	12	15.1 / 6.36	9.39	11.4 / 5.17	6.55	7.91 / 3.64	4.13	5.38 / 2.32	1.56	2.37 / 0.927
Node 312	Piper Creek below Township Road 374	81	59	N	*Prorated*[3]	26.4	62.3 / 9.37	24.7	54.2 / 9.03	22.4	45 / 8.65	20.5	37.8 / 8.22	17.6	28.7 / 7.46	14.3	20.5 / 6.56	13	17.7 / 6.23	11.2	14.5 / 5.7	9.79	12.1 / 5.09	7.68	9.13 / 4.14	5.36	6.32 / 2.91	3.37	4.3 / 1.85	1.26	1.9 / 0.742

Note:

1) Flow Type: N: Natural; NZ: Naturalized Flows.
2) Regionalization: Instantaneous flood flows were derived based on regional analysis.
3) Prorated: Instantaneous flood flows were estimated by applying ratio between effective drainage area at the node in interest and node upstream or downstream of the node in interest using regional area power factor.
4) 2-year flood adjusted based on interpolation of values from upstream and downstream nodes.

4.2.1.2 Major Tributaries

Flood frequency estimates for the major tributaries of Red Deer River for various return periods were obtained for Fallentimber Creek near Sundre, Bearberry Creek near Sundre, James River near Sundre, Little Red Deer River near the Mouth, Medicine River near Eckville, Waskasoo Creek at Red Deer, and Blindman near Blackfalds using recorded annual maximum instantaneous flow series.

Appendix A provides the annual maximum instantaneous flows used for the flood frequency analysis and the relationships established between the annual maximum daily and instantaneous flows to estimate missing annual instantaneous flows. The flood frequency estimates based on the best distribution fits using non-parametric Anderson-Darling test are recommended for the Red Deer River tributaries.

The data used in the flood frequency analyses for the major tributaries are described below.

Bearberry Creek near Sundre

The flow records for Bearberry Creek near Sundre are available at WSC Station No. 05CA002 (with a gross and effective drainage area of 237.5 km^2) for the period 1978 to 2016.

Fallentimber Creek near Sundre

The flow records for Fallentimber Creek near Sundre are available at WSC Station No. 05CA012 (with a gross and effective drainage area of 488.8 km^2) for the period 1978 to 2016.

James River near Sundre

The flow records for James River near Sundre are available at WSC Station No. 05CA011 (with a gross and effective drainage area of 821.4 km^2) for the period 1966 to 2016.

Little Red Deer River near the Mouth

The flow records for Little Red Deer River near the Mouth are available at WSC Station No. 05CB001 (with a gross drainage area of 2,578.3 km^2 and an effective drainage area of 2,439.2 km^2) for the period 1960 to 2016.

Medicine River near Eckville and at the Mouth

Medicine River at the Mouth has an effective drainage area of 2,674 km^2. The flow records for Medicine River are available near Eckville (WSC Station No. 05CC007, a gross drainage area of 1,915.9 km^2 and an effective drainage area of 1,857.3 km^2) for the period 1962 to 2016. The annual maximum instantaneous flow series for Medicine River at the Mouth was derived based on the recorded data at Medicine River near Eckville, the ratio of the effective drainage areas, and the area power factor derived based on the regional relationship (see Figure 4.2).

Waskasoo Creek at Red Deer

The flow records for Waskasoo Creek at Red Deer (WSC Station No. 05CC001, a gross drainage area of 487 km^2 and an effective drainage area of 250 km^2) are available for the period 1984 to 2016.

Blindman River near Blackfalds

The flow records for Blindman River near Blackfalds (WSC Station No. 05CC007, a gross drainage area of 1915.9 km^2 and an effective drainage area of 1857.3 km^2) are available for the periods 1916 to 1922 and 1962 to 2016.

4.2.2 Regional Analysis

4.2.2.1 Ungauged Locations along Red Deer River

The flood frequency estimates at the ungauged locations along the study reach of the Red Deer River were estimated based on a regional relationship established between drainage area and flood flow estimates for various return periods for the Red Deer River watershed upstream of Dickson Dam (see Figure 4.1). Drainage areas at the WSC station locations were obtained from the WSC hydrometric data. Drainage areas at ungauged locations were estimated based on the known drainage areas at the upstream or downstream WSC stations by adding or subtracting, respectively, the estimated local areas between the WSC stations and the location of interest.

4.2.2.2 Ungauged Tributaries

The flood frequency estimates for ungagged tributaries (e.g., three locations along Piper Creek and two locations along Waskasoo Creek) were obtained based on the results of a regional flood frequency analysis. Table 4.2 provides the names, station numbers, and drainage areas of the WSC stations used in the regional analysis.

The empirical relationships between drainage area and flood frequency estimates were established for the return periods ranging from 2 to 1,000 years. The relationships were then used to derive the flood frequency estimates for ungauged tributaries.

The flood frequency estimates for the ungauged tributaries were obtained as follows:

- Drainage areas at WSC stations were provided by WSC. Gross drainage areas at the ungauged tributary locations were estimated using a GIS analysis (see Figure 1.1).
- Flood frequency estimates for the WSC stations (see Appendix C) were obtained based on the natural annual maximum instantaneous flow series.
- The regional relationships between drainage area and peak discharge for a range of return periods (i.e., 2 to 1,000 years) were developed as shown in Figures 4.1 and 4.2.
- The resulting regional relationships were then used to estimate the flood peak discharges at the ungauged locations for the various return periods, as summarized below:
  - The flood frequency estimates for Piper Creek above Waskasoo Creek were obtained based on the flood frequency estimates for Waskasoo Creek at Red Deer and the regional drainage area power factor.
  - The flood frequency estimates for Piper Creek below Highway 595 and Piper Creek below Township Road 374 were obtained based on the flood frequency estimates for Piper Creek above Waskasoo Creek and the regional drainage area power factor.
  - The flood frequency estimates for Waskasoo Creek above Piper Creek and Waskasoo Creek below Highway 42 were obtained based on the flood frequency estimates for Waskasoo Creek at Red Deer and the regional drainage area power factor.
- The resulting flood frequency estimates at the ungauged locations are provided in Table 4.2.

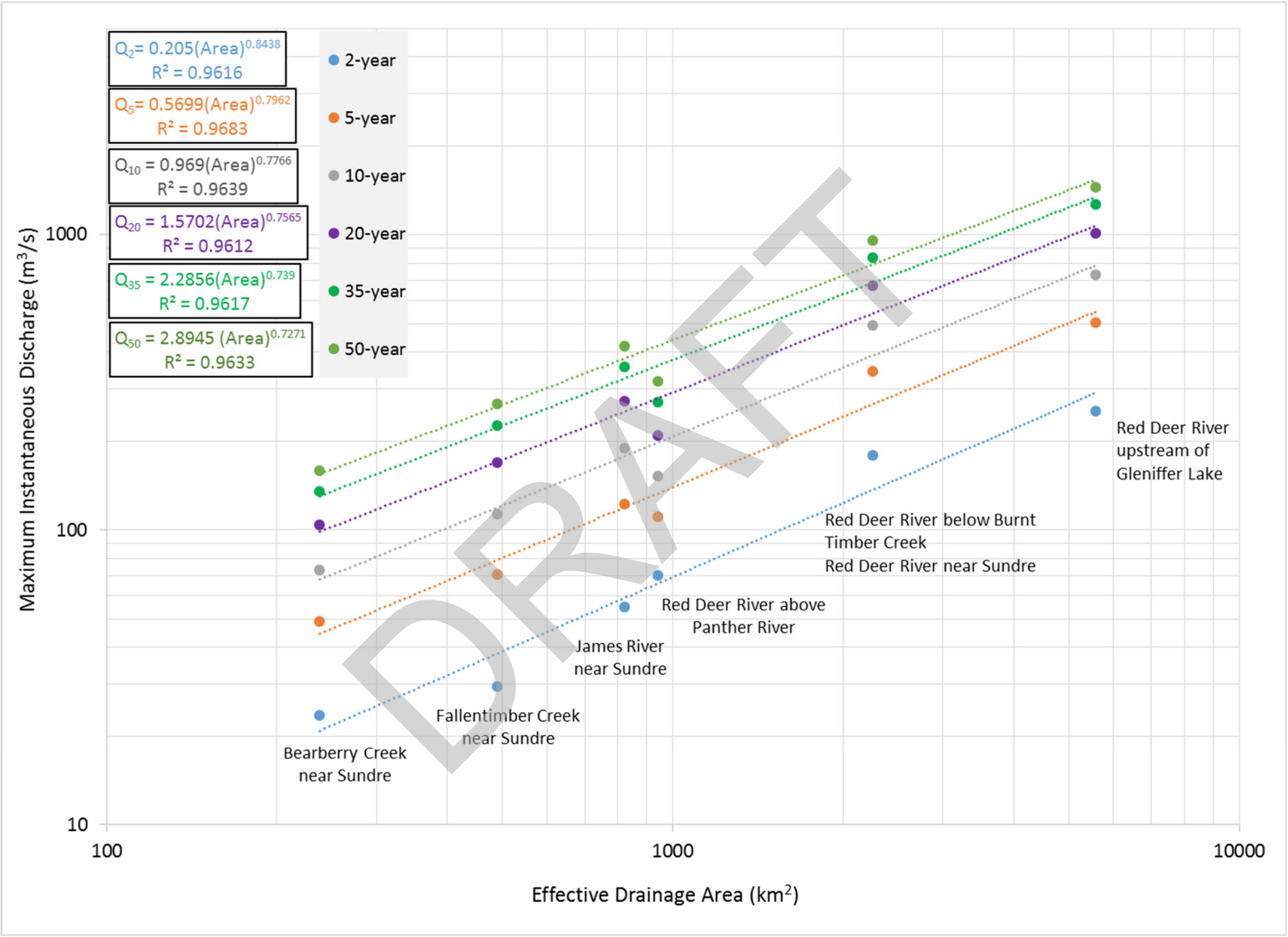

Figure 4.1a: Empirical Relationships – Red Deer River and Tributaries Upstream of Dickson Dam (2- to 50-year Return Period)

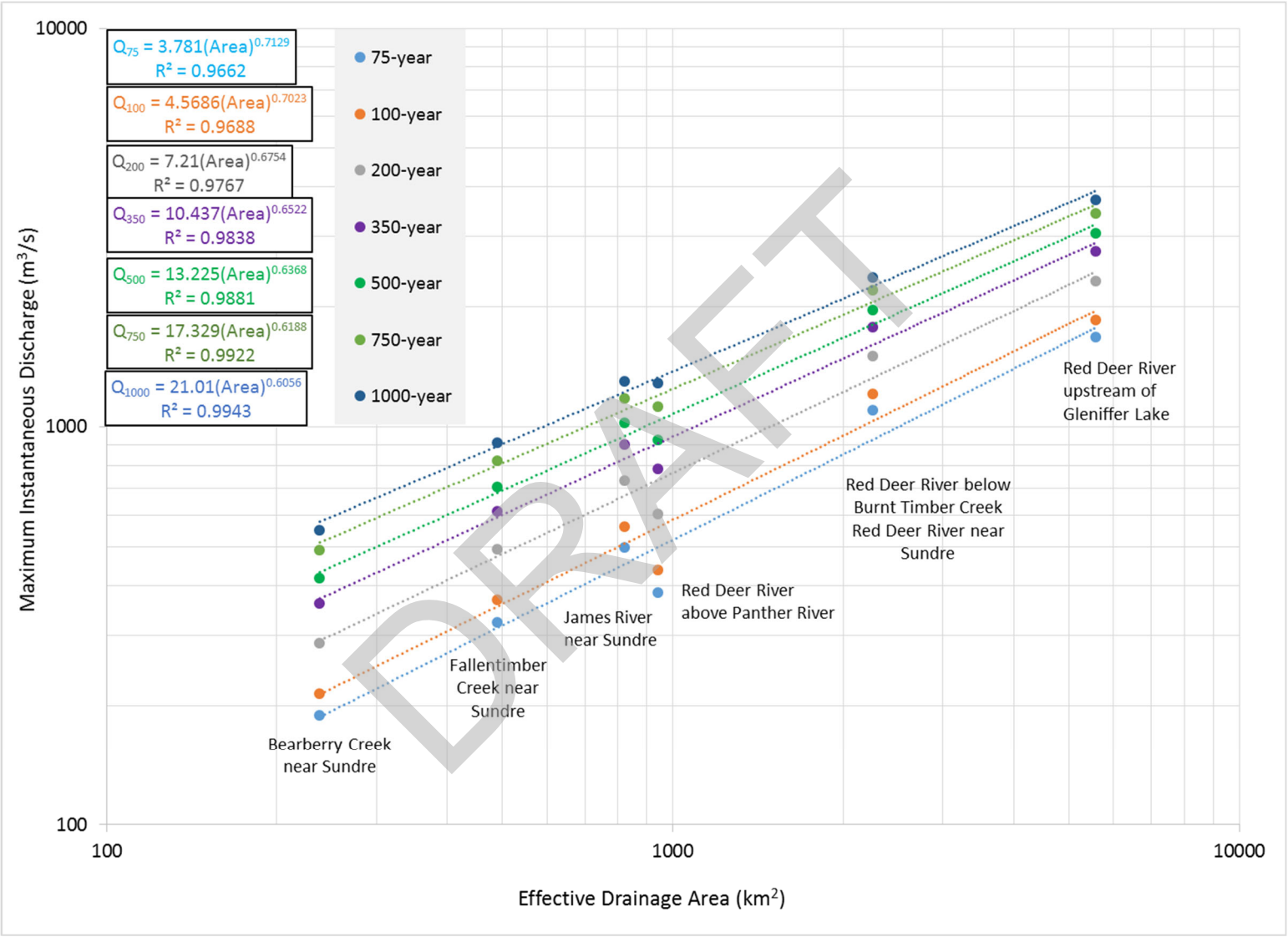

Figure 4.1b: Empirical Relationships – Red Deer River and Tributaries Upstream of Dickson Dam (75- to 1000-year Return Period)

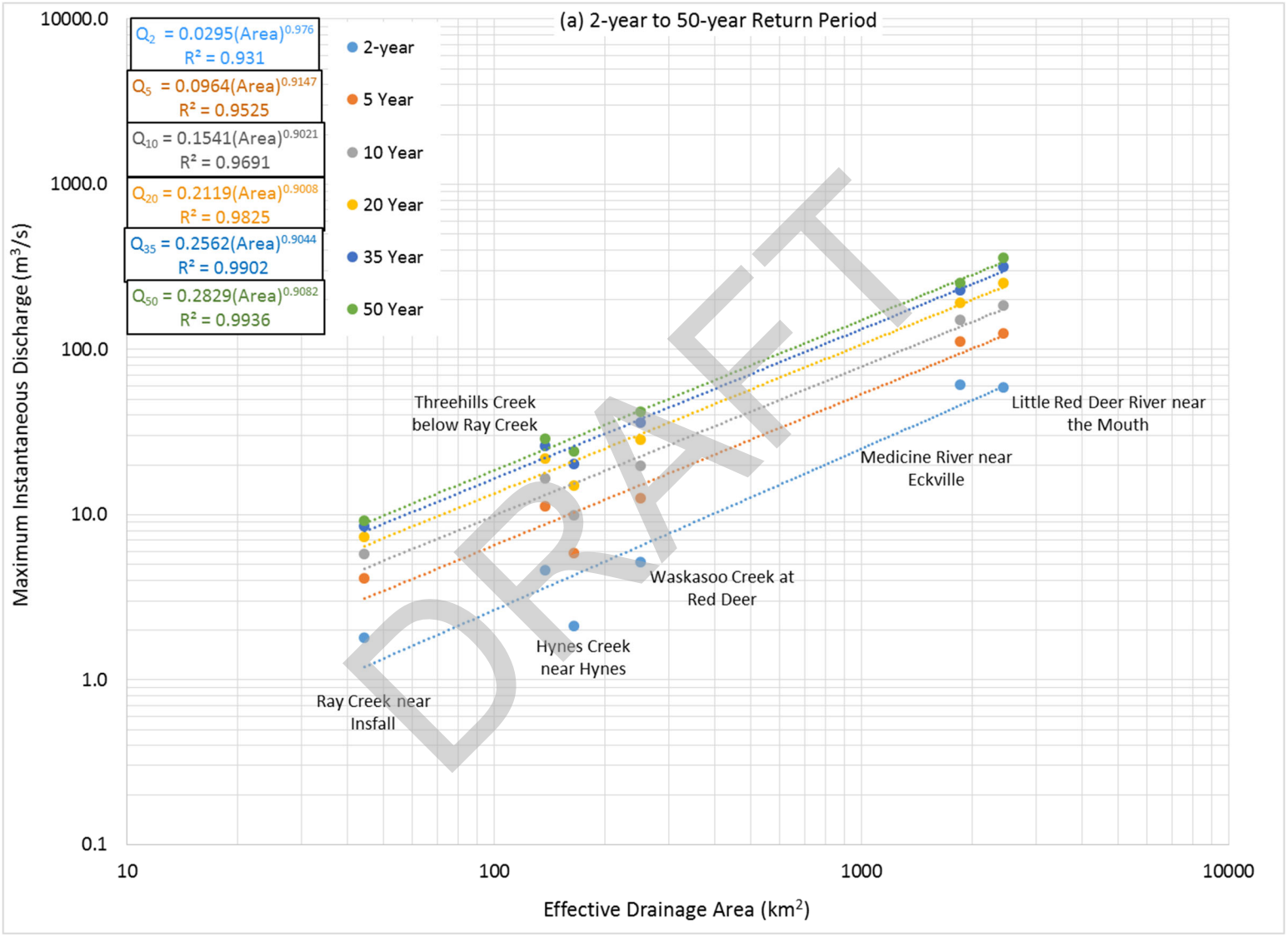

Figure 4.2a: Empirical Relationships – Red Deer River and Tributaries Downstream of Dickson Dam (2- to 50-year Return Period)

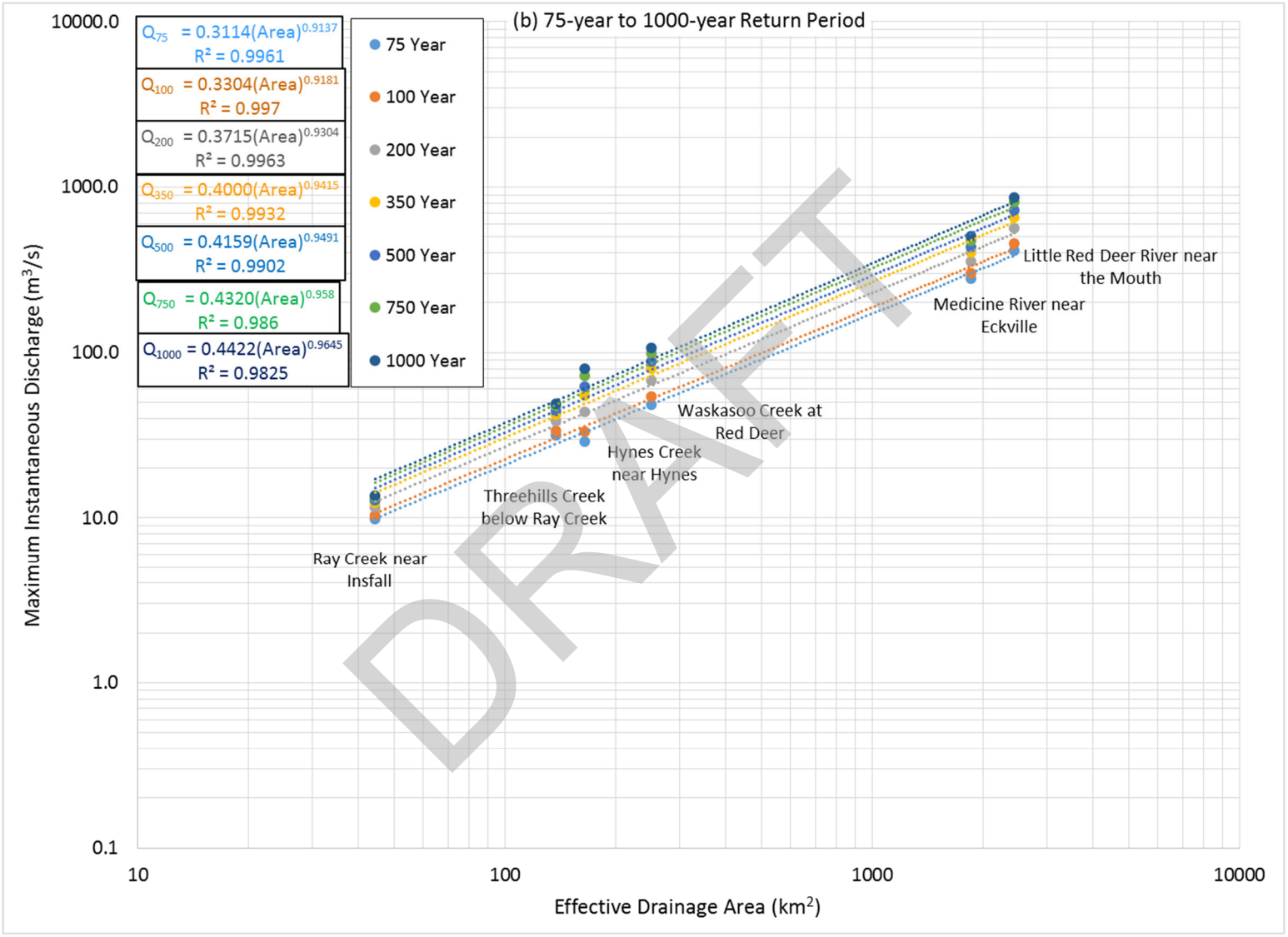

Figure 4.2b: Empirical Relationships – Red Deer River and Tributaries Downstream of Dickson Dam (75- to 1000-year Return Period)

Table 4.2: Results of Regional Flood Frequency and Single Station Transfer Analysis

WSC Station Name / Location of Interest	Regional Analysis (RA) / Single Station Transfer (SST) Approach[1]	Latitude	Longitude	Gross Drainage Area (km^2)	Effective Drainage Area (km^2)	Computed Instantaneous Flood Flows (m^3/s)[1]												
						1000-year	750-year	500-year	350-year	200-year	100-year	75-year	50-year	35-year	20-year	10-year	5-year	2-year
Red Deer River above Fallentimber Creek	RA using Upstream Red Deer Region stations	51° 45' 14"	-114° 39' 11"	2,616	2,616	2,470	2,260	1,980	1,770	1,470	1,150	1,030	884	767	604	437	300	157
Red Deer River below Fallentimber Creek	RA using Upstream Red Deer Region stations	51° 45' 39"	-114° 38' 58"	3,146	3,146	2,760	2,530	2,230	1,990	1,660	1,310	1,180	1,010	879	695	504	347	183
Red Deer River above Bearberry Creek	RA using Upstream Red Deer Region stations	51° 47' 55"	-114° 37' 56"	3,213	3,213	2,790	2,560	2,260	2,020	1,680	1,330	1,200	1,030	892	706	513	353	187
Red Deer River below Bearberry Creek	RA using Upstream Red Deer Region stations	51° 48' 14"	-114° 37' 50"	3,451	3,451	2,920	2,680	2,370	2,120	1,770	1,390	1,260	1,080	941	745	542	374	198
Red Deer River above James River	RA using Upstream Rd Deer Region stations	51° 54' 06"	-114° 34' 24"	3,586	3,586	2,990	2,740	2,430	2,170	1,810	1,430	1,290	1,110	968	767	558	385	205
Red Deer River below James River	RA using Upstream Red Deer Region stations	51° 54' 44"	-114° 32' 38"	4,459	4,459	3,410	3,140	2,790	2,500	2,100	1,670	1,510	1,300	1,140	905	661	458	246
Red Deer River at Garrington Bridge	RA using Upstream Red Deer Region stations	51° 56' 35"	-114° 28' 59"	4,530	4,699	3,500	3,230	2,870	2,580	2,170	1,720	1,560	1,350	1,180	937	685	476	256
Red Deer River above Raven River	RA using Upstream Red Deer Region stations	52° 01' 46"	-114° 22' 10"	4,777	4,777	3,550	3,280	2,910	2,620	2,200	1,750	1,590	1,370	1,200	953	698	484	261
Waskasoo Creek at Red Deer (WSC Station No. 05CC001)	Recorded Flows	52°16'06"	-113°47'59"	487	250	107	99.0	88.7	80.2	67.7	53.9	48.7	41.8	36.3	28.3	19.8	12.7	5.16
Waskasoo Creek above Piper Creek	SST using Waskasoo Creek at Red Deer - Downstream Red Deer Region Power	52° 15' 28"	-113° 48' 36"	326	166	72.0	67.0	60.2	54.6	46.3	37.1	33.5	28.9	25.1	19.6	13.7	8.71	3.47
Waskasoo Creek below Highway 42	SST using Waskasoo Creek at Red Deer - Downstream Red Deer Region Power	52° 08' 33"	-113° 43' 41"	243	142	61.8	57.5	51.8	47.0	40.0	32.1	29.0	25.0	21.7	17.0	11.9	7.54	2.97
Piper Creek above Waskasoo Creek	SST using Waskasoo Creek at Red Deer - Downstream Red Deer Region Power	52° 15' 22"	-113° 48' 31"	156	82.0	36.3	33.9	30.7	28.0	23.9	19.3	17.5	15.2	13.2	10.3	7.21	4.55	1.73
Piper Creek below Highway 595	SST using Waskasoo Creek at Red Deer - Downstream Red Deer Region Power	52° 13' 49"	-113° 48' 10"	120	73.0	32.8	30.6	27.7	25.3	21.7	17.5	15.9	13.8	12.0	9.39	6.55	4.13	1.56
Piper Creek below Township Road 374	SST using Waskasoo Creek at Red Deer - Downstream Red Deer Region Power	52° 12' 04"	-113° 44' 56"	81	59.0	26.4	24.7	22.4	20.5	17.6	14.3	13.0	11.2	9.79	7.68	5.36	3.37	1.26

Note:

1) Where the Regional Analysis approach uses Upstream or Downstream of Red Deer Region stations, instantaneous flood flows were derived using regression formulae presented in the Figures 4.1 and 4.2, respectively.

4.3 Regulated Flow Scenarios

4.3.1 Methods

Dickson Dam is the only major structure that is located within the study area and has regulation effects on flood flows in Red Deer River downstream of the dam. The following two methods were used to generate flood flow estimates for the regulated flow scenario, in order to assess flood frequencies using two different methods:

1) Daily Flow Routing: The naturalized daily flow series was routed through Gleniffer Lake using reservoir operation rules. The resulting daily reservoir outflows were routed along the study reach, considering daily flow series from tributary watersheds and travel times along the Red Deer River main stem. Ultimately, the annual maximum instantaneous regulated flow series were established for all of the locations and used in the flood frequency analysis to generate flood flow estimates.

2) Synthetic Flood Hydrograph Routing: A series of synthetic inflow hydrographs with flood peaks corresponding to the naturalized maximum instantaneous flood flows for all thirteen return periods were routed through Gleniffer Lake using reservoir operation rules. The resulting reservoir outflow hydrographs were routed along the study reach downstream of Dickson Dam, assuming additional floods from tributary watersheds and considering Red Deer River travel times.

The results based on the above two methods were compared to provide a basis for selecting the most appropriate flood frequency estimates for all required locations downstream of Dickson Dam (see Section 4.4).

4.3.1.1 Daily Flow Routing

The daily flow routing method involved derivation of regulated daily flows for the Red Deer River immediately downstream of Dickson Dam by running a modified version of the Water Resources Management Model (WRMM) (AENV 2002). The model was run using a daily interval for the period 1912 to 2016, using the naturalized daily flow series computed for this study and current reservoir operation rules (see Appendix B for details).

The SSARR model (a component of the modified WRMM) was then used to route the computed regulated daily flow series along the rest of the Red Deer River study reach downstream of Dickson Dam, considering Red Deer River travel times and additional daily inflows from tributaries and local runoff.

The following method was used to generate the regulated daily flow series at various locations:

- Generated the daily flow series at the mouth of each major tributary (i.e., Little Red Deer River, Medicine River, Waskasoo Creek, and Blindman River) using the recorded flows at the WSC gauging stations, scaling flows as required using ratios of relevant drainage areas.
- Routed the regulated daily Red Deer flow series along the rest of the study reach downstream of Gleniffer Lake, considering travel times and additional daily inflows from tributaries and local runoff.

Different methods were used to estimate regulated flows before and after 1962, when records for all major tributaries (i.e., Little Red Deer River, Medicine River, Waskasoo Creek, and Blindman River) became available. Flows for the period 1962 to 2016 were estimated first, using all available records and the methods detailed in Table 4.3. Flows for the period 1912 to 1961 (i.e., prior to available flow record for all tributaries), were estimated as follows:

1) For each month, correlated regulated daily flows for Red Deer River at Red Deer were correlated with the regulated daily flow series generated at each location for the period 1962 to 2016.

2) The regulated daily flow series at each location for the period 1912 to 1961 was generated using the relationship established in Step 1), as outlined in Table 4.3.

Table 4.3: Data and Method used for Generating the Regulated Daily Flow Series

Location	Method
Red Deer River downstream of the Little Red Deer River confluence	■ The regulated daily flow series for the period 1912 to 1959 was generated based on the regulated daily flows for Red Deer River at Red Deer and the monthly relationship established using the regulated flows for the period 1962 to 2016. ■ The regulated daily flow series for the period 1960 to 2016 was generated using the regulated dally flow series for Red Deer River below Gleniffer Lake and the recorded natural flows for Little Red River near the Mouth (WSC Station No. 05CB001).
Red Deer River downstream of the Medicine River confluence	■ The regulated daily flow series for the period 1912 to 1961 was generated based on the regulated daily flows for Red Deer River below Gleniffer Lake and the estimated combined daily flows from Little Red Deer River and Medicine River at the Mouth for the period 1912 to 1961. ■ Estimated combined daily flows from the two tributaries for the period 1912 to 1961 were assumed to be the difference between the regulated daily flows for Red Deer River at Red Deer and Red Deer River below Gleniffer Lake. ■ The regulated daily flow series for the period 1962 to 2016 was generated using the generated data for Red Deer River downstream of the Little Red Deer confluence and the estimated natural flows for Medicine River at the Mouth (based on the recorded data at WSC Station No. 05CC007).
Red Deer River upstream of the City of Red Deer	■ The regulated daily flow series for the period 1912 to 1961 was generated based on the regulated daily flows for Red Deer River at Red Deer and the monthly relationship established using the regulated flows for the period 1962 to 2016. ■ The regulated daily flow series for the period 1962 to 2016 was generated using the regulated flow data for Red Deer River below Medicine River, considering the additional drainage area and travel times.
Red Deer River at the City of Red Deer	■ The regulated daily flow series was generated using the naturalized flows in Red Deer River at Red Deer, considering the effect of flow regulation at Dickson Dam.
Red Deer River below the Waskasoo Creek confluence	■ The regulated daily flow series for the period 1912 to 1983 was generated based on the regulated daily flows for Red Deer River at Red Deer and the monthly relationship established using the regulated flows for the period 1983 to 2016. ■ The regulated daily flow series for the period 1983 to 2016 was generated using the regulated flows for Red Deer River at Red Deer and the recorded natural flows in Waskasoo Creek at Red Deer (WSC Station No. 05CC011).
Red Deer River above the Blindman River confluence	■ The regulated daily flow series for the period 1912 to 1961 was generated based on the regulated daily flows for Red Deer River at Red Deer and the monthly relationship established using the regulated flows for the period 1962 to 2016. ■ The regulated daily flow series for the period 1962 to 2016 was generated using the regulated flow data for Red Deer River below the Waskasoo Creek confluence, considering travel times.
Red Deer River below the Blindman River confluence	■ The regulated daily flow series for the period 1912 to 1915 and 1924 to 1961 was generated based on the regulated daily flows for Red Deer River at Red Deer and the monthly relationship established using the regulated flows for the period 1962 to 2016. ■ The regulated daily flow series for the periods 1916 to 1923 and 1962 to 2016 was generated using the regulated flows in Red Deer River above the Blindman River confluence and the recorded natural flows in Blindman River near Blackfalds (WSC Station No. 05CC001).
Red Deer River at Highway 11	■ The regulated daily flow series for the period 1912 to 1961 was generated based on the regulated daily flows for Red Deer River at Red Deer and the monthly relationship established using the regulated flows for the period 1962 to 2016. ■ The regulated daily flow series for the period 1962 to 2016 was generated using the generated regulated flow data for Red Deer River below the Blindman River confluence, considering the additional drainage area and travel times.

The annual maximum daily regulated flow series were converted to the annual maximum instantaneous regulated flow series using the relationships established for the Red Deer River at Red Deer based on the regulated flow series (i.e., recorded data after 1983) for all of the locations between Dickson Dam and Highway 11 (see Figure A4 in Appendix A).

Table 4.4 presents the resulting flood frequency estimates and the corresponding upper and lower confidence intervals for the regulated flows. The annual maximum instantaneous regulated flow series used in the flood frequency analysis are provided in Appendix A.

4.3.1.2 Synthetic Flood Hydrograph Routing

The synthetic hydrograph routing method involved routing a series of synthetic flood inflow hydrographs through Gleniffer Lake and farther downstream. Inflow hydrographs were prepared for thirteen return periods (i.e., the 2-year to 1,000-year floods), with peaks corresponding to the naturalized maximum instantaneous flood flows estimated upstream of Gleniffer Lake. The resulting reservoir outflow hydrographs were routed along the Red Deer River downstream of Dickson Dam. The SSARR model was used to route the flood hydrographs along the Red Deer River, assuming flood contributions from tributary watersheds based on pattern of historical flood events as follows:

- Concurrent storm events for the Little Red Deer River watershed (e.g., if 2-year flood event occurred in the Red Deer River similar flood is expected for Little Red Deer River watershed); and
- For all flood magnitudes on the Red Deer River, 2-year flood events are assumed for Medicine River, Waskasoo Creek, and Blindman River.

Synthetic inflow flood hydrographs with hourly time steps were developed using appropriate volumes associated with the maximum instantaneous discharges for the various return periods. The synthetic inflow flood hydrographs were derived to closely represent a typical shape corresponding to recorded hydrographs for the Red Deer River above Gleniffer Lake. The procedure used to derive the inflow hydrographs is described below:

1) Derived the flood volumes associated with the flood hydrographs containing the naturalized annual maximum instantaneous flood flows.
2) Established the relationships between the flood volumes derived in Step 1) and the corresponding annual maximum instantaneous natural/naturalized discharges of the various flood events (see Figure 4.3).
3) Estimated the total flood volumes associated with the peak discharges for the 2-, 5-, 10-, 20-, 35-, 50-, 75-, 100-, 200-, 350-, 500-, 750-, and 1000-year return period floods using the relationships established in Step 2).
4) Identified and created typical synthetic hourly flood hydrographs representative of the flood runoff responses of the catchments based on the historical records for the Gleniffer Lake and tributary rivers and creeks along the study reach (see Figures 4.4 and 4.5).
5) Estimated and established average times to peak from the start of the rising limb of the flood hydrograph to a time of flood peak occurrence based on the historical flood hydrographs.
6) Developed synthetic inflow flood hydrographs considering the total volumes, magnitudes of flood peaks, times to peak, and typical shapes of hourly flood hydrograph for the various return periods. This involved adjusting the initial hydrographs based on the typical shapes to closely match the estimated flood volumes.

7) Routed the inflow flood hydrographs through Gleniffer Lake and downstream of Dickson Dam to generate the regulated flood peak discharges for the various return periods.

The regulated flood peak flow estimates derived downstream of major tributaries using this method can be considered relatively conservative because of the assumption of concurrent storm event from the Little Red Deer River and assumption of elevation of 946 m, which is the historical upper limit for the reservoir regulation in the middle of June, as starting reservoir water level during flood inflows. The results are used to evaluate and illustrate the attenuation effects of Gleniffer Lake for a range of flood events (i.e., 2-year to 1,000-year floods). The flood frequency estimates for various locations along the study reach of Red Deer River were selected based on the results obtained using the two methods (see Section 4.3.3).

The flood hydrographs were developed with peaks corresponding to the naturalized 2-year to 1,000-year maximum instantaneous flood flows derived in this study. The reservoir routing of the inflow flood hydrographs was conducted following the current flood control guidelines (or operation rules provided in Appendix B) and the assumed starting reservoir water level of 946.0 m. Golder developed an in-house tool in Microsoft Excel™ for the reservoir routing analysis that considered pre-spilling 36 hours before the flood peaks of all flood events.

The resulting inflows to and outflows from Gleniffer Lake are provided in Figures C.3-1 to C.3-3 in Appendix C. The resulting outflow hydrographs from Gleniffer Lake were routed along the downstream reach of the Red Deer River to estimate the regulated flood flows at the various locations using the SSARR model, considering the travel times along the river and additional inflows of the flood hydrographs from the tributaries.

Figures C.3-4 to C.3-9 in Appendix C provide the flood hydrographs at various locations along the study reach of the Red Deer River. Table 4.5 presents the resulting flood frequency estimates for various return periods for the regulated flows using the synthetic flood hydrograph method. The 95% upper and lower confidence intervals are also estimated using the ratio of flood frequency estimates for natural/naturalized and regulated flow conditions and confidence intervals estimated for natural/naturalized flow conditions.

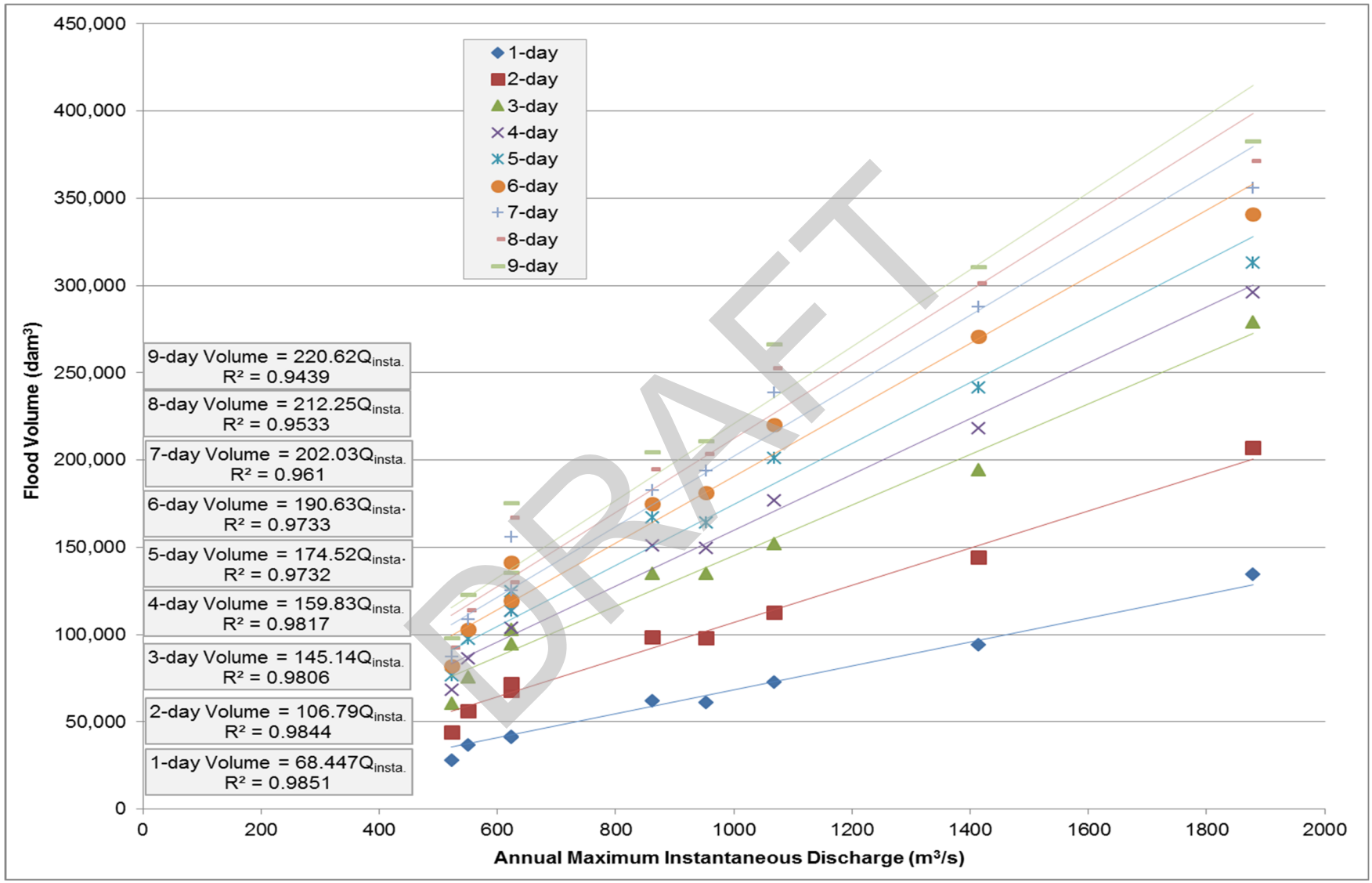

Figure 4.3: Relationships between Flood Volumes and Annual Maximum Instantaneous Discharges

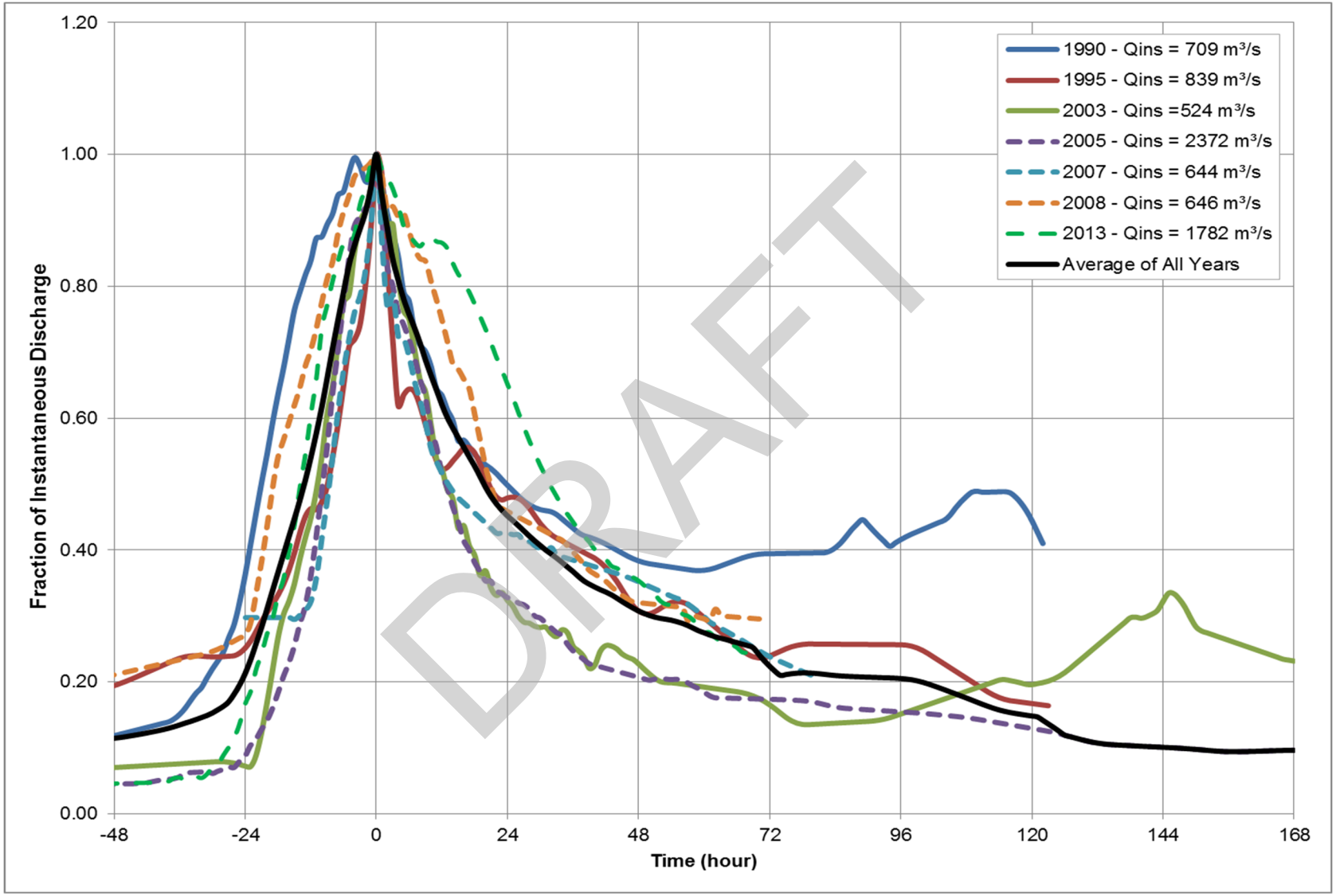

Figure 4.4: Typical Inflow Flood Hydrograph to Gleniffer Lake Derived Based on the Historical Flood Hydrographs

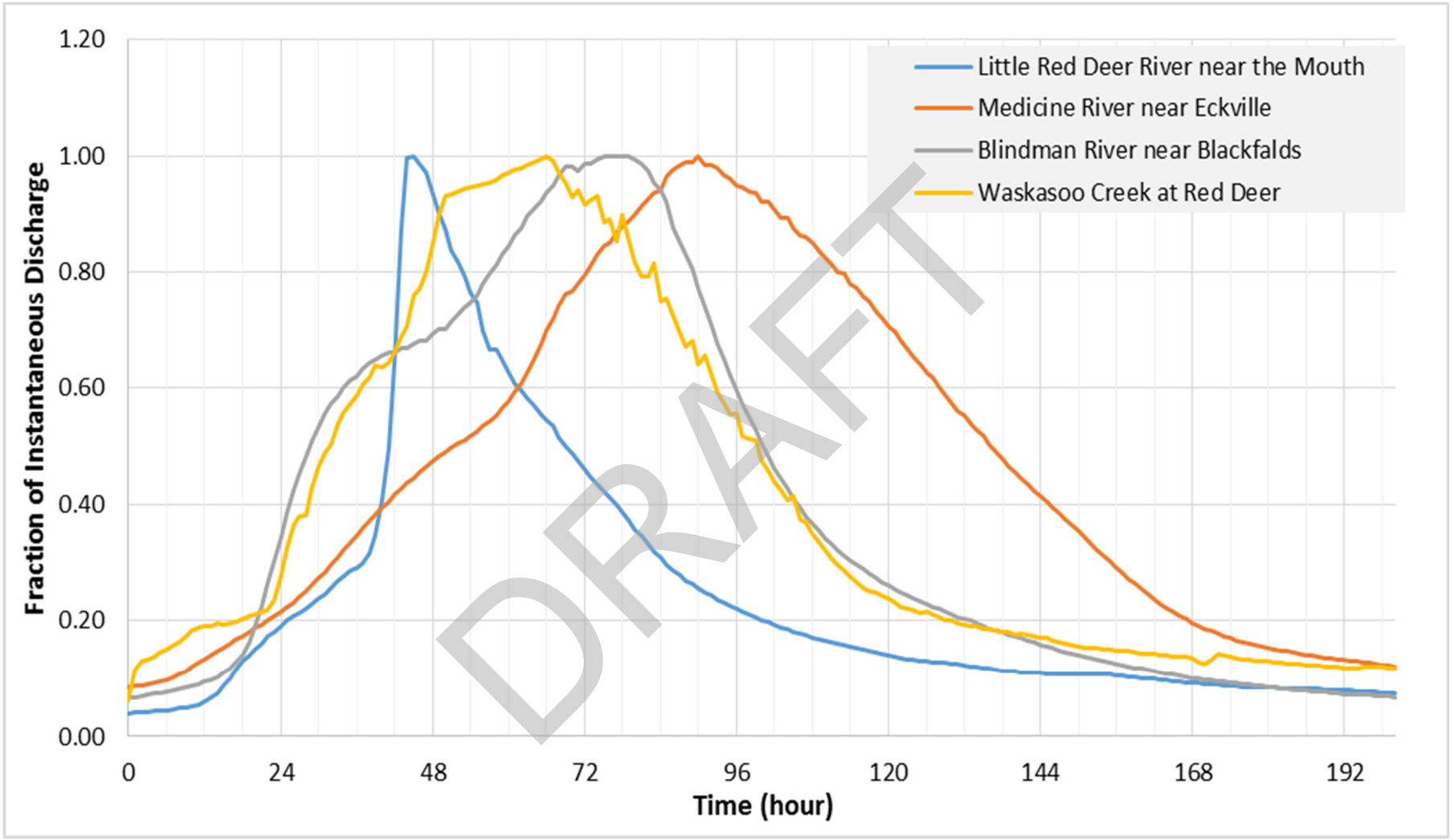

Figure 4.5: Typical Synthetic Flood Hydrograph Derived for Tributaries Based on the Historical Flood Hydrographs

Table 4.4: Flood Frequency Estimates – Regulated Flows using Annual Daily Flood Flow Series

WSC Station ID / Node ID	WSC Station Name or Location of Interest	Effective Drainage Area (km²)	Flow Type[1]	Distribution	Recommended Instantaneous Flood Flows (m³/s)																							
					1000-yr		750-yr		500-yr		350-yr		200-yr		100-yr		75-yr		50-yr		35-yr		20-yr		10-yr		5-yr		2-yr	
					Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower
RED DEER RIVER																												
Node 108	Red Deer River downstream of Dickson Dam	5,583	R	3P(MLH)	2,470	4,370 1,550	2,290	3,950 1,450	2,050	3,420 1,330	1,850	3,040 1,220	1,570	2,460 1,070	1,260	1,880 899	1,140	1,670 834	992	1,390 740	869	1,190 661	696	898 553	512	625 420	355	418 297	185	218 157
Node 109	Red Deer River Downstream of Little Red Deer River Confluence	8,022	R	3P(MLH)	1,730	6,280 2,230	1,630	5,680 2,080	1,500	4,910 1,910	1,400	4,370 1,750	1,240	3,530 1,540	1,050	2,700 1,290	979	2,400 1,200	881	2,000 1,060	799	1,710 950	676	1,290 795	534	898 603	402	601 427	234	313 226
Node 110	Red Deer River Downstream of Medicine River	10,696	R	3P(MLH)	1,800	8,370 2,970	1,710	7,570 2,770	1,590	6,550 2,550	1,480	5,830 2,330	1,330	4,710 2,050	1,150	3,600 1,720	1,080	3,200 1,600	977	2,670 1,410	893	2,280 1,270	768	1,720 1,060	619	1,200 804	478	801 569	290	417 301
Node 111	Red Deer River upstream of Red Deer	10,966	R	3P(MLH)	1,630	8,580 3,050	1,550	7,760 2,840	1,440	6,720 2,610	1,350	5,980 2,390	1,220	4,830 2,100	1,060	3,690 1,760	994	3,280 1,640	907	2,740 1,450	833	2,340 1,300	720	1,760 1,090	586	1,230 824	457	821 583	282	428 309
Node 202	Red Deer River at Red Deer (WSC Station No. 05CC002)	11,052	R	3P(MLH)	1,630	8,650 3,070	1,550	7,820 2,860	1,440	6,770 2,630	1,350	6,030 2,410	1,220	4,870 2,120	1,060	3,720 1,770	994	3,310 1,650	907	2,760 1,460	833	2,360 1,310	720	1,770 1,100	586	1,240 830	457	827 588	282	431 311
Node 112	Red Deer River below Waskasoo Creek	11,302	R	3P(MLH)	1,630	8,850 3,140	1,550	8,000 2,920	1,440	6,920 2,690	1,350	6,170 2,460	1,220	4,980 2,170	1,060	3,800 1,810	995	3,380 1,690	908	2,820 1,490	834	2,410 1,340	721	1,810 1,120	587	1,270 849	458	846 601	283	441 318
Node 113	Red Deer River above Blindman River	11,302	R	3P(MLH)	1,630	8,850 3,140	1,550	8,000 2,920	1,440	6,920 2,690	1,350	6,170 2,460	1,220	4,980 2,170	1,060	3,800 1,810	995	3,380 1,690	908	2,820 1,490	834	2,410 1,340	721	1,810 1,120	587	1,270 849	458	846 601	283	441 318
Node 114	Red Deer River below Blindman River	13,336	R	3P(MLH)	1,620	10,400 3,710	1,550	9,440 3,450	1,460	8,170 3,170	1,380	7,280 2,900	1,250	5,880 2,560	1,110	4,480 2,140	1,050	3,990 1,990	964	3,330 1,760	892	2,840 1,580	782	2,140 1,320	647	1,500 1,000	512	998 709	320	520 375
Node 115	Red Deer River at Highway 11	13,454	R	3P(MLH)	1,560	10,500 3,740	1,500	9,520 3,480	1,410	8,240 3,200	1,340	7,340 2,930	1,220	5,930 2,580	1,080	4,520 2,160	1,020	4,030 2,010	945	3,360 1,780	876	2,870 1,590	770	2,160 1,330	640	1,510 1,010	508	1,010 715	318	525 378

Note:

1) Flow Type: R: Regulated Flows

Table 4.5: Flood Frequency Estimates – Regulated Flows using Synthetic Hydrographs

WSC Station ID / Node ID	WSC Station Name or Location of Interest	Flow Type[1]	Distribution	Recommended Instantaneous Flood Flows (m^3/s)																							
				1000-yr		750-yr		500-yr		350-yr		200-yr		100-yr		75-yr		50-yr		35-yr		20-yr		10-yr		5-yr		2-yr	
				Flood Est.	Upper Lower	Flood Est.	Upper Lower	Flood Est.	Upper Lower	Flood Est.	Upper Lower	Flood Est.	Upper Lower	Flood Est.	Upper Lower	Flood Est.	Upper Lower	Flood Est.	Upper Lower	Flood Est.	Upper Lower	Flood Est.	Upper Lower	Flood Est.	Upper Lower	Flood Est.	Upper Lower	Flood Est.	Upper Lower
RED DEER RIVER																											
Node 108	Red Deer River downstream of Dickson Dam	R	*Synthetic Hydrograph*[2]	3,250	12,908 2,591	2,920	11,128 2,395	2,470	8,997 2,071	2,250	7,763 1,924	1,830	5,831 1,647	1,310	3,788 1,235	1,160	3,225 1,116	966	2,524 959	811	2,000 825	597	1,366 639	395	809 442	240	456 280	154	264 182
Node 109	Red Deer River Downstream of Little Red Deer River Confluence	R	*Synthetic Hydrograph*[2]	4,110	8,696 2,736	3,700	7,594 2,481	3,180	6,256 2,172	2,900	5,515 2,014	2,390	4,296 1,679	1,760	2,902 1,275	1,570	2,505 1,149	1,330	2,018 1,000	1,130	1,646 858	850	1,161 658	578	738 460	364	436 297	212	245 179
Node 110	Red Deer River Downstream of Medicine River	R	*Synthetic Hydrograph*[2]	4,420	9,352 2,943	4,000	8,210 2,682	3,460	6,807 2,363	3,150	5,991 2,188	2,620	4,709 1,841	1,950	3,215 1,412	1,750	2,792 1,281	1,480	2,246 1,113	1,270	1,850 964	969	1,324 750	672	858 534	433	519 354	256	295 216
Node 111	Red Deer River upstream of Red Deer	R	*Synthetic Hydrograph*[2]	3,810	9,703 2,626	3,500	8,582 2,439	3,100	7,190 2,181	2,830	6,254 2,023	2,390	4,887 1,733	1,820	3,369 1,354	1,630	2,884 1,220	1,390	2,311 1,061	1,200	1,881 924	926	1,326 728	648	838 525	424	506 348	254	290 206
05CC002. / Node 202	Red Deer River at Red Deer (WSC Station No. 05CC002)	R	*Synthetic Hydrograph*[2]	3,810	6,884 2,531	3,500	6,179 2,351	3,100	5,323 2,129	2,830	4,742 1,981	2,390	3,805 1,712	1,820	2,710 1,343	1,630	2,363 1,217	1,390	1,948 1,062	1,200	1,632 932	926	1,204 741	648	799 533	424	498 356	254	294 214
Node 112	Red Deer River below Waskasoo Creek	R	*Synthetic Hydrograph*[2]	3,910	6,845 2,658	3,590	6,160 2,466	3,190	5,317 2,239	2,910	4,725 2,077	2,460	3,819 1,813	1,870	2,744 1,411	1,680	2,413 1,288	1,430	1,995 1,114	1,230	1,659 971	948	1,218 762	661	807 544	432	505 364	257	297 218
Node 113	Red Deer River above Blindman River	R	*Synthetic Hydrograph*[2]	3,870	6,517 2,565	3,570	5,908 2,401	3,150	5,067 2,165	2,880	4,538 2,015	2,440	3,704 1,759	1,860	2,670 1,381	1,670	2,346 1,271	1,430	1,949 1,110	1,230	1,627 973	947	1,199 762	661	800 543	432	504 365	256	297 220
Node 114	Red Deer River below Blindman River	R	*Synthetic Hydrograph*[2]	4,440	7,491 2,936	4,130	6,859 2,781	3,630	5,873 2,488	3,310	5,237 2,316	2,810	4,276 2,036	2,180	3,153 1,635	1,980	2,782 1,507	1,720	2,345 1,336	1,490	1,971 1,179	1,150	1,455 925	808	975 666	529	616 447	301	349 258
Node 115	Red Deer River at Highway 11	R	*Synthetic Hydrograph*[2]	4,420	7,457 2,922	4,110	6,826 2,768	3,610	5,841 2,474	3,290	5,205 2,302	2,790	4,246 2,022	2,180	3,153 1,635	1,970	2,768 1,499	1,710	2,331 1,328	1,490	1,971 1,179	1,150	1,455 925	806	973 664	528	614 446	300	348 257

Note:

1) Flow Type: R: Regulated Flows
2) Synthetic Hydrographs: Instantaneous flood flows were derived based on routing of regulated synthetic hydrographs

4.3.2 Comparison of Two Methods

Figures C3-10 to C3-18 in Appendix C provide comparison of flood frequency estimates for natural/naturalized flow conditions, regulated flow conditions using daily flow routing, and regulated flow conditions using synthetic hydrography routing methods. Comparison of the results of regulated flood frequency estimates using the two methods indicates the following:

- The differences in the flood frequency estimates using the two methods are large for the return periods greater than 20 years, and the differences increase with increasing return periods.
- For the Red Deer River below the Little Red Deer River:
  - the flood frequency estimates based on the regulated daily flow series are higher than those based on routing the synthetic flood hydrographs for the return periods of 2 and 5 years, with the differences varying from 6% to 17%; and
  - the flood frequency estimates for the Red Deer River below the Little Red Deer River based on the regulated daily flow series are lower than those based on routing the synthetic flood hydrographs for the return periods of 10 years and greater, with the differences varying from 3% to 183%.
- For the Red Deer River below Dickson Dam:
  - the flood frequency estimates based on the regulated daily flow series are higher than those based on routing the synthetic flood hydrographs for the return periods up to 50 years, with the differences varying from 3% to 32%; and
  - the flood frequency estimates based on the regulated daily flow series are lower than those based on routing the synthetic flood hydrographs for the return periods of 75 years and greater, with the differences varying from 2% to 22%.

4.3.3 Recommendation

Flood frequency estimates obtained for Red Deer River below Dickson Dam is using 105 years of regulated daily flow series routed through Gleniffer Lake. Since these data include floods series up to a 100-year flood, the flood frequency estimates based on both method reflect the actual effect of flow regulation. However, there are large uncertainties with flood estimates for return periods greater than the 100-year due to data limitation (e.g., the uncertainty associated with the 1000-years flood frequency estimate is significantly very high since we are only using 105 years of recorded data). Hence, flood frequency estimates for return periods more than 100-years are mostly a function of extension of best fitting curves to the limited number of data, with plotting position less than 100-year return period. Therefore, it is important to realize the effect of the number of years of recorded data when one wants to assess the effect of flood attenuation by Gleniffer Lake.

The length of recorded flood data for the Red Deer River tributaries are also very limited. For example, for Little Red Deer River, recorded flood data is only available for 55 years (1961 to 2015). The flood of June 2005 is the only flood that is larger than the 20-year return period flood. Hence, there are large uncertainties with flood estimates downstream of the tributaries for return periods greater than the 20-year due to data limitation.

Based on comparison of plots (i.e., Figures C3-10 to C3-18 in Appendix C) the flood frequency estimates based on the regulated daily flow series are significantly less than flood frequency estimates for natural/naturalized flow conditions for return periods greater than 35-years. This indicates an increase in the amount of flood attenuations by Gleniffer Lake with increase in flood magnitudes. However, routing of the synthetic hydrographs through Gleniffer Lake and downstream reach of Red Deer River, indicate a relatively consistent flood attenuations in flood magnitudes with relatively less attenuation with increase in flood magnitude.

To reduce the uncertainties associated with data limitation, it is recommended to use flood frequency estimates obtained based on the regulated daily flow series for return period up to 20-years and flood frequency estimates based on the synthetic hydrograph for return period greater than 20-years.

4.4 Comparison to Previous Studies

Table 4.6 and Table 4.7 present a comparison of the flood frequency estimates obtained in this study for key locations (e.g., Red Deer River below Burnt Timber Creek, Red Deer River at Dickson Dam, and Red Deer River at Red Deer) with those in the previous studies for the same locations.

Table 4.6: Comparison of Flood Frequency Estimates – Red Deer River

Return Period (years)	Natural/Naturalized Flows (m^3/s)				Regulated Flows (m^3/s)			
	AEP(1980)	AENV (1991)	Golder (2014a)	Current Study	AEP (1980)	AENV (1991)	Golder (2014a)	Current Study
Red Deer River below Burnt Timber Creek								
2	Not Applicable	Not Applicable	186	180	Not Applicable	Not Applicable	Not Applicable	Not Applicable
5	Not Applicable	Not Applicable	338	343	Not Applicable	Not Applicable	Not Applicable	Not Applicable
10	Not Applicable	Not Applicable	489	493	Not Applicable	Not Applicable	Not Applicable	Not Applicable
20	Not Applicable	Not Applicable	688	671	Not Applicable	Not Applicable	Not Applicable	Not Applicable
50	801	Not Applicable	1,050	954	Not Applicable	Not Applicable	Not Applicable	Not Applicable
100	940	Not Applicable	1,440	1,210	Not Applicable	Not Applicable	Not Applicable	Not Applicable
200	1,076	Not Applicable	1,960	1,510	Not Applicable	Not Applicable	Not Applicable	Not Applicable
500	Not Applicable	Not Applicable	2,940	1,970	Not Applicable	Not Applicable	Not Applicable	Not Applicable
1,000	Not Applicable	Not Applicable	3,980	2,370	Not Applicable	Not Applicable	Not Applicable	Not Applicable
Red Deer River below Dickson Dam								
2	Not Applicable	Not Applicable	Not Applicable	254	Not Applicable	Not Applicable	Not Applicable	185
5	Not Applicable	Not Applicable	Not Applicable	503	Not Applicable	Not Applicable	Not Applicable	355
10	Not Applicable	Not Applicable	Not Applicable	733	Not Applicable	Not Applicable	Not Applicable	512
20	Not Applicable	Not Applicable	Not Applicable	1,010	Not Applicable	Not Applicable	Not Applicable	696

Table 4.6: Comparison of Flood Frequency Estimates – Red Deer River

Return Period (years)	Natural/Naturalized Flows (m^3/s)				Regulated Flows (m^3/s)			
	AEP(1980)	AENV (1991)	Golder (2014a)	Current Study	AEP (1980)	AENV (1991)	Golder (2014a)	Current Study
50	1,272	Not Applicable	Not Applicable	1,450	768	Not Applicable	Not Applicable	966
100	1,472	Not Applicable	Not Applicable	1,850	988	Not Applicable	Not Applicable	1,310
200	1,677	Not Applicable	Not Applicable	2,320	1,124	Not Applicable	Not Applicable	1,830
500	Not Applicable	Not Applicable	Not Applicable	3,060	Not Applicable	Not Applicable	Not Applicable	2,470
1,000	Not Applicable	Not Applicable	Not Applicable	3,710	Not Applicable	Not Applicable	Not Applicable	3,250
Red Deer River at Red Deer								
2	Not Applicable	333	Not Applicable	359	Not Applicable	333	300	282
5	Not Applicable	663	Not Applicable	677	Not Applicable	555	534	457
10	Not Applicable	913	Not Applicable	959	Not Applicable	870	731	586
20	Not Applicable	1,160	Not Applicable	1,280	Not Applicable	967	958	720
50	1,648	1,490	Not Applicable	1,790	1,002	1,210	1,320	1,390
100	1,902	1,740	Not Applicable	2,250	1,252	1,470	1,650	1,820
200	2,152	1,990	Not Applicable	2,760	1,416	1,710	2,050	2,390
500	Not Applicable	Not Applicable	Not Applicable	3,550	Not Applicable	Not Applicable	2,690	3,100
1,000	Not Applicable	Not Applicable	Not Applicable	4,240	Not Applicable	Not Applicable	3,290	3,810

m^3/s = cubic metres per second.

Table 4.7: Comparison of Flood Frequency Estimates – Red Deer River Tributaries

Return Period (years)	Natural Flows (m^3/s)					
	AEP (1992)	AENV (1995)	AEP (1997)	AMEC (2007)	Golder (2014a)	Current Study
Fallentimber Creek near Sundre						
2	Not Applicable	Not Applicable	Not Applicable	Not Applicable	40.0	29.5
5	Not Applicable	Not Applicable	Not Applicable	Not Applicable	84.0	70.5
10	Not Applicable	Not Applicable	Not Applicable	Not Applicable	128	113
20	Not Applicable	Not Applicable	Not Applicable	Not Applicable	186	169
50	Not Applicable	Not Applicable	Not Applicable	Not Applicable	293	268
100	Not Applicable	Not Applicable	Not Applicable	Not Applicable	408	367
200	Not Applicable	Not Applicable	Not Applicable	Not Applicable	562	492
500	Not Applicable	Not Applicable	Not Applicable	Not Applicable	853	705
1,000	Not Applicable	Not Applicable	Not Applicable	Not Applicable	1,160	911
Bearberry Creek near Sundre						
2	Not Applicable	Not Applicable	25.0	Not Applicable	24.0	23.6
5	Not Applicable	Not Applicable	54.0	Not Applicable	55.0	49.2
10	Not Applicable	Not Applicable	75.0	Not Applicable	87.0	73.3
20	Not Applicable	Not Applicable	96.0	Not Applicable	126	104
50	Not Applicable	Not Applicable	124	Not Applicable	194	158
100	Not Applicable	Not Applicable	145	Not Applicable	258	214
200	Not Applicable	Not Applicable	Not Applicable	Not Applicable	336	286
500	Not Applicable	Not Applicable	Not Applicable	Not Applicable	467	416
1,000	Not Applicable	Not Applicable	Not Applicable	Not Applicable	580	550
James River near Sundre						
2	Not Applicable	Not Applicable	Not Applicable	Not Applicable	59.0	54.9
5	Not Applicable	Not Applicable	Not Applicable	Not Applicable	123	122
10	Not Applicable	Not Applicable	Not Applicable	Not Applicable	184	189
20	Not Applicable	Not Applicable	Not Applicable	Not Applicable	261	274
50	Not Applicable	Not Applicable	Not Applicable	Not Applicable	400	420
100	Not Applicable	Not Applicable	Not Applicable	Not Applicable	544	561
200	Not Applicable	Not Applicable	Not Applicable	Not Applicable	731	735
500	Not Applicable	Not Applicable	Not Applicable	Not Applicable	1,070	1,030
1,000	Not Applicable	Not Applicable	Not Applicable	Not Applicable	1,420	1,300

Table 4.7: Comparison of Flood Frequency Estimates – Red Deer River Tributaries

Return Period (years)	Natural Flows (m^3/s)					
	AEP (1992)	AENV (1995)	AEP (1997)	AMEC (2007)	Golder (2014a)	Current Study
Little Red Deer River near the Mouth						
2	Not Applicable	Not Applicable	Not Applicable	50.0	59.0	58.6
5	Not Applicable	Not Applicable	Not Applicable	105	125	125
10	Not Applicable	Not Applicable	Not Applicable	158	185	184
20	Not Applicable	Not Applicable	Not Applicable	221	255	252
50	Not Applicable	Not Applicable	Not Applicable	324	366	360
100	Not Applicable	Not Applicable	Not Applicable	419	464	455
200	Not Applicable	Not Applicable	Not Applicable	532	577	563
500	Not Applicable	Not Applicable	Not Applicable	711	751	728
1,000	Not Applicable	Not Applicable	Not Applicable	874	903	871
Medicine River at the Mouth						
2	Not Applicable	Not Applicable	Not Applicable	65.0	84.0	87.8
5	Not Applicable	Not Applicable	Not Applicable	114	145	156
10	Not Applicable	Not Applicable	Not Applicable	151	190	209
20	Not Applicable	Not Applicable	Not Applicable	189	238	267
50	Not Applicable	Not Applicable	Not Applicable	242	309	353
100	Not Applicable	Not Applicable	Not Applicable	283	368	424
200	Not Applicable	Not Applicable	Not Applicable	327	433	503
500	Not Applicable	Not Applicable	Not Applicable	388	529	618
1,000	Not Applicable	Not Applicable	Not Applicable	436	610	714
Waskasoo Creek at Red Deer						
2	7.50	Not Applicable	Not Applicable	Not Applicable	10.0	5.16
5	18.2	Not Applicable	Not Applicable	Not Applicable	17.0	12.7
10	26.8	Not Applicable	Not Applicable	Not Applicable	23.0	19.8
20	35.7	Not Applicable	Not Applicable	Not Applicable	29.0	28.3
50	48.6	Not Applicable	Not Applicable	Not Applicable	36.0	41.8
100	59.0	Not Applicable	Not Applicable	Not Applicable	43.0	53.9
200	70.1	Not Applicable	Not Applicable	Not Applicable	49.0	67.7
500	Not Applicable	Not Applicable	Not Applicable	Not Applicable	59.0	88.7
1,000	Not Applicable	Not Applicable	Not Applicable	Not Applicable	66.0	107

Table 4.7: Comparison of Flood Frequency Estimates – Red Deer River Tributaries

Return Period (years)	Natural Flows (m^3/s)					
	AEP (1992)	AENV (1995)	AEP (1997)	AMEC (2007)	Golder (2014a)	Current Study
Waskasoo Creek above Confluence with Piper Creek						
2	3.20	Not Applicable	Not Applicable	Not Applicable	Not Applicable	3.47
5	7.90	Not Applicable	Not Applicable	Not Applicable	Not Applicable	8.71
10	11.7	11.7	Not Applicable	Not Applicable	Not Applicable	13.7
20	15.7	Not Applicable	Not Applicable	Not Applicable	Not Applicable	19.6
50	21.6	21.6	Not Applicable	Not Applicable	Not Applicable	28.3
100	26.4	26.4	Not Applicable	Not Applicable	Not Applicable	37.1
200	31.6	Not Applicable	Not Applicable	Not Applicable	Not Applicable	46.3
Piper Creek above Confluence with Waskasoo Creek						
2	5.30	Not Applicable	Not Applicable	Not Applicable	Not Applicable	1.73
5	13.9	Not Applicable	Not Applicable	Not Applicable	Not Applicable	4.55
10	19.3	Not Applicable	Not Applicable	Not Applicable	Not Applicable	7.21
20	26.1	Not Applicable	Not Applicable	Not Applicable	Not Applicable	10.3
50	35.9	Not Applicable	Not Applicable	Not Applicable	Not Applicable	15.2
100	44.0	Not Applicable	Not Applicable	Not Applicable	Not Applicable	19.3
200	52.7	Not Applicable	Not Applicable	Not Applicable	Not Applicable	23.9
Blindman River near Blackfalds						
2	Not Applicable	Not Applicable	Not Applicable	Not Applicable	57.0	50.4
5	Not Applicable	Not Applicable	Not Applicable	Not Applicable	105	102
10	Not Applicable	Not Applicable	Not Applicable	Not Applicable	144	150
20	Not Applicable	Not Applicable	Not Applicable	Not Applicable	190	206
50	Not Applicable	Not Applicable	Not Applicable	Not Applicable	263	295
100	Not Applicable	Not Applicable	Not Applicable	Not Applicable	330	375
200	Not Applicable	Not Applicable	Not Applicable	Not Applicable	411	468
500	Not Applicable	Not Applicable	Not Applicable	Not Applicable	541	612
1,000	Not Applicable	Not Applicable	Not Applicable	Not Applicable	662	739

m^3/s = cubic metres per second.

The previous flood frequency estimates were obtained based on the recorded data available for the studies. For example, the 2014 study by Golder was based on the data up to 2013, including the preliminary estimates of the June 2013 flood peak discharges. This study is based on the updated estimates of the June 2013 flood peak discharges and the preliminary flow data for the 2015 and 2016 floods from WSC. In addition, this study includes the analyses to update the relationships between annual maximum daily and instantaneous flows at the various locations.

The comparison in Table 4.6 for Red Deer River indicates that the flood peak discharge estimates are generally comparable for natural/naturalized flood flow series. The estimates from the 1980 study are generally lower than those from the other three studies for all locations. Use of the revised relationships between maximum instantaneous and daily flows, three additional years of flow data, the updated flood flow estimates for the June 2013, and different frequency distribution fits used in this study, are the main reasons for the differences between the two Golder studies for the flood frequency estimates.

The comparison in Table 4.7 for the Red Deer River tributaries indicates that the flood peak discharges estimates are generally comparable, and the difference can be attributed to additional data, updated relationships used between maximum instantaneous and daily flows, and difference in frequency fit used for various studies. However, the flood estimates obtained for Piper Creek above confluence with Waskasoo Creek in the AENV (1992) study is significantly higher than the values derived for the current study and also higher than the flood estimates obtained for Waskasoo Creek above confluence with Piper Creek, though the drainage area of Waskasoo Creek is almost twice the drainage area of Piper Creek.

5.0 CLIMATE CHANGE COMMENTARY

Past studies on the effect of climate change (e.g., Martz et al. 2007) indicate that climate change could result in increased air temperature, more frequent drought and water shortages, increased precipitation in some areas, and increased flooding. As a result of climate change and variability, many regions of Canada, including the Prairies, could experience warmer air temperatures and changes in stream flow magnitude and timing (e.g., higher winter stream flows and lower summer stream flows).

Prediction of future scenarios is influenced by the climate model used for the prediction. Future scenarios involve prediction of precipitation to increase in Alberta, with less precipitation falling as snow and more rainfall-on-snow precipitation events (Valeo et al. 2007). It is anticipated that such changes in precipitation patterns could increase the frequency and intensity of extreme events (i.e., flood, drought, hail, and windstorms). For the Red Deer River watershed, it is predicted that if rain-on-snow events occur more frequently and the snowpack begins to melt earlier, then flood events could occur earlier in the spring than in the past.

Using the predictions from the Canadian Regional Climate Model, Valeo et al. (2007) showed that May precipitation could increase by more than 35% under a 2xCO2 scenario. As a result, the expected increases in precipitation during the month of May could nearly double spring flood peak flows.

As part of the Hydro-Climate Modelling Study for South Saskatchewan River for AEP, Golder (2010) analyzed the hydrologic effects of several scenarios of forecasted future climate change for the entire Red Deer River watershed. The hydrologic assessment used down-scaled temperature and precipitation changes predicted by five Global Circulation Models and associated scenarios (i.e., average and four worst temperature-precipitation conditions) and for two future time periods [i.e., 2011 to 2040 (2020s) and 2041 to 2070 (2050s)]. The results of climate change analysis indicate that the changes in the 25-year flood peak discharge in the Red Deer River near Sundre range from 5% increase to 21% decrease by 2020s, and from 6% increase to 14% decrease by 2050s.

Islam and Gan (2015) used a physically-based land surface scheme, the Modified Soil Biosphere Atmosphere (MISBA), to assess the future stream flows of the South Saskatchewan River Basin of Alberta, which includes the Bow River and its tributaries, under the combined impacts of climate change and El Nino Southern Oscillation (ENSO). Under climate change projections alone or a combined impact of climate change and ENSO, the annual mean flow in the Red Deer River is expected to decrease. However, the mean spring (March to May) flow is projected to increase by 2%, 9%, and 9% in 2020s, 2050s, and 2080s, respectively. In contrast, the mean summer (June to August) flow in the Red Deer River at Drumheller is projected to decrease by 30%, 25%, and 20% in 2020s, 2050s, and 2080s, respectively.

The 2005 and 2013 floods in the Red Deer River basin have been the largest floods since 1915, as illustrated by the plots of annual maximum instantaneous flows in Figure 5.1. Based on the recorded flow data over the past 105 years (i.e., 1912 to 2016), the observed annual peak flows in Red Deer River in recent years do not appear to be increasing with time. The trend in Red Deer River appears to be a decreasing one, although the trend is not statistically significant.

Approximately 70% to 80% of the recorded annual peak flows in Red Deer River occurred during the period May to July as shown in Table 5.1 and Figure 5.2. The frequency of annual peak flows occurring during this period does not appear to be changing with time. The recent patterns in the timing of the annual peak flows are similar to what were observed at the beginning of the century. There is no clear evidence that the patterns in magnitude or timing of annual peak flows have changed significantly over the past hundred years.

Table 5.1: Timings of Annual Maximum Daily Flows in the Red Deer River

Month	Red Deer River Inflow to Gleniffer Lake - Occurrences of Annual Maximum Daily Flows Since 1912		Red Deer River at Red Deer - Occurrences of Annual Maximum Daily Flows Since 1912	
	Number	%	Number	%
April	4	4	20	19
May	15	14	14	13
June	56	54	41	39
July	17	16	18	17
August	9	9	8	8
September	3	3	3	3

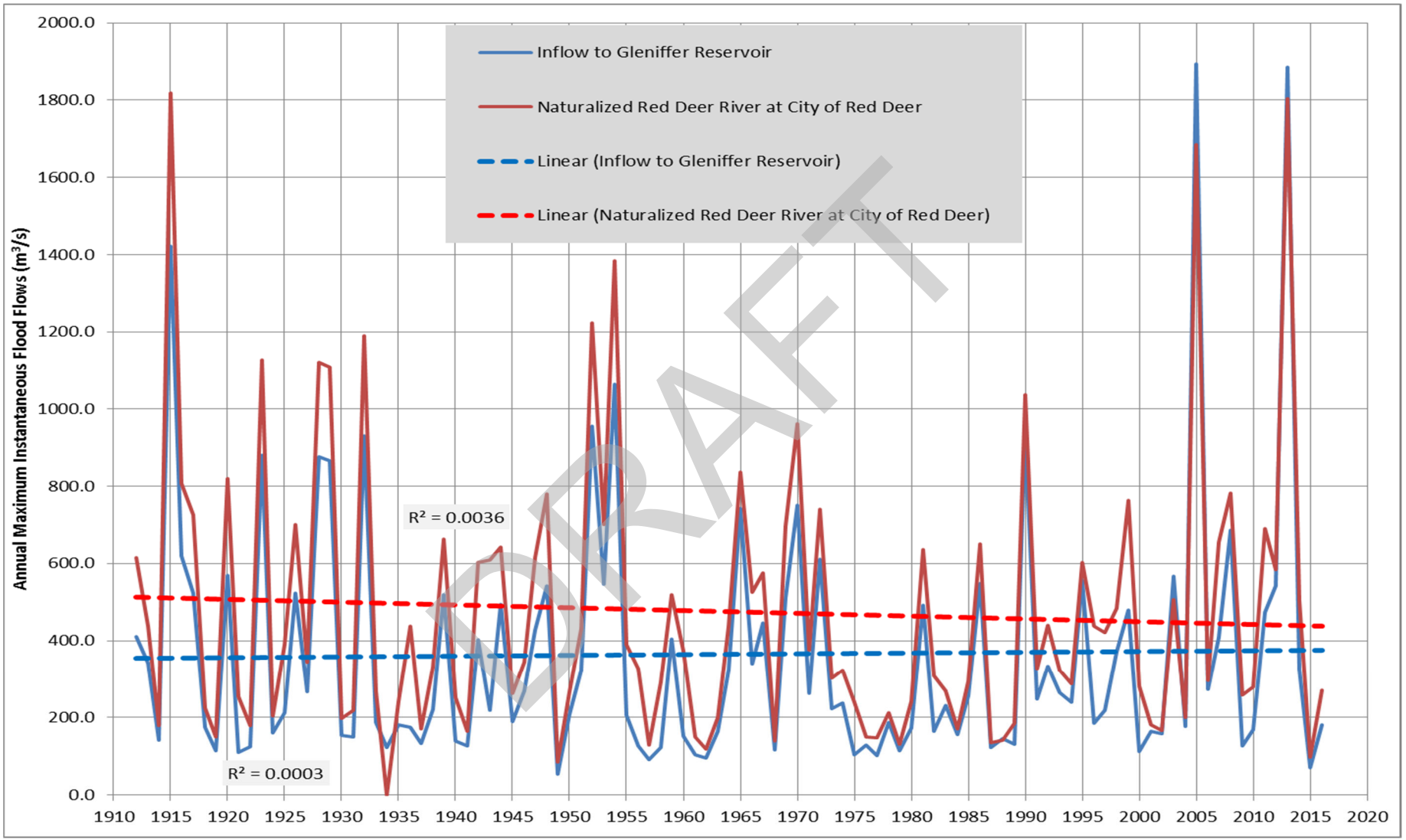

Figure 5.1: Annual Peak Flows Series for the Red Deer River

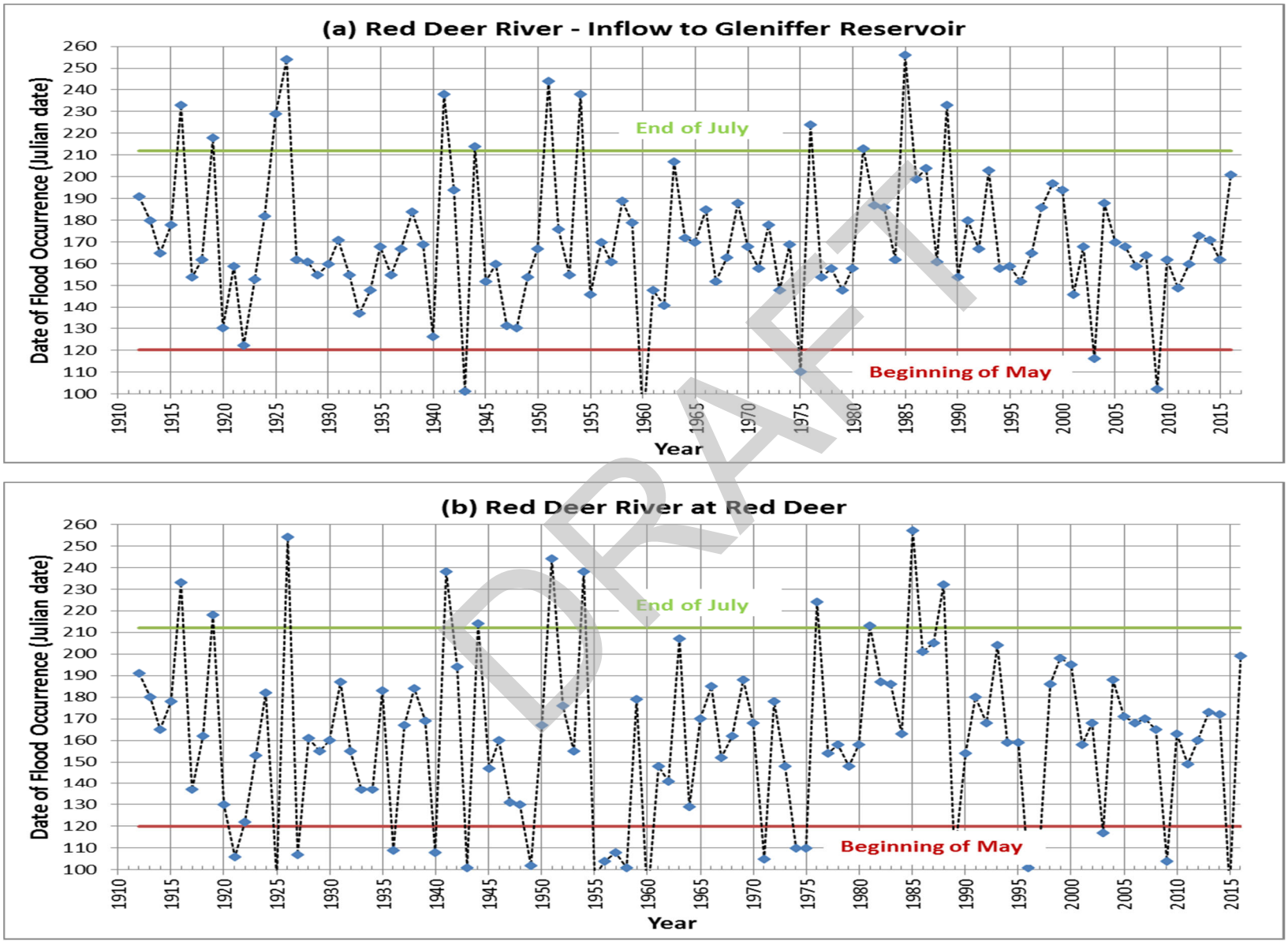

Figure 5.2: Timings of Past Annual Peak Flows in the Red Deer River

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The results of this study support the following conclusions:

- The flood frequency estimates obtained in this study are the most up-to-date for the various locations along the study reach of Red Deer River between the Burnt Timber Creek confluence and Highway 11. These locations include those downstream of the major tributary (i.e., Fallentimber Creek, Bearberry Creek, James River, Little Red Deer River, Medicine River, Waskasoo Creek, and Blindman River) confluences, and the City of Red Deer.
- This study includes use of the preliminary estimates of the annual maximum flows in 2015 and 2016 by WSC. Inclusion of the additional flow information and the updated 2013 flood peak discharges, increases the sample sizes for the flood frequency analyses and reliability of the resulting flood frequency estimates.
- Application of the RBAT and WRMM models, including use of the SSARR channel routing procedures, provides an accurate basis to simulate and account for the storage effects of Gleniffer Lake on the flood flows downstream of Dickson Dam. The resulting natural/naturalized and regulated flood flow series provide good data sets for the flood frequency analyses.
- The flood frequency estimates based on the natural/naturalized flow series in this study are comparable to those obtained in the 1980 and 2014 studies. For example, the estimated 100-year flood peak discharge in Red Deer River at Red Deer is 2,160 m^3/s in this study, which compares to 1,902 m^3/s in the 1980 study.

6.2 Recommendations

Tables 6.1 and 6.2 provide summaries of the recommended estimates of instantaneous flood peak discharges for return periods ranging from 2 to 1,000 years for both the natural/naturalized and regulated flow conditions. The 95% upper and lower confidence intervals are provided where applicable.

The maximum record length available and used in the flood frequency is less than 100 years, except for Red Deer River at Red Deer, which is 105 years. Therefore, there are large uncertainties (i.e., the confidence intervals are large) associated with the flood frequency estimates for return periods greater than 100 years.

For the regulated flow scenario, flood frequency estimates obtained based on the regulated daily flow series for return period up to 20-years and flood frequency estimates based on the synthetic hydrograph for return period of 35-years and above are recommended in Table 6.2. The daily flow series do not contain extreme flood event information. Therefore, the synthetic flood hydrograph method provides a more conservative and reliable basis for evaluating the flow regulation effects of the large flood events. This basis of recommendation is suitable for the river flood modelling and hazard assessment of the studies.

Table 6.1: Final Flood Frequency Estimates - Natural and Naturalized Flows - Adjusted

WSC Station ID / Node ID	WSC Station Name or Location of Interest	Gross Drainage Area (km²)	Effective Drainage Area (km²)	Flow Type[1]	Distribution	Recommended Instantaneous Flood Flows\ (m³/s)																							
						1000-yr		750-yr		500-yr		350-yr		200-yr		100-yr		75-yr		50-yr		35-yr		20-yr		10-yr		5-yr		2-yr	
						Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower
RED DEER RIVER																													
05CA009 / Node 200	Red Deer River below Burnt Timber Creek (WSC Station No. 05CA009)	2,246	2,246	N	3P(MLH)	2,370	6,630 / 1,330	2,200	5,910 / 1,260	1,970	4,990 / 1,150	1,780	4,250 / 1,060	1,510	3,300 / 926	1,210	2,390 / 776	1,100	2,080 / 719	954	1,680 / 640	837	1,390 / 574	671	1,020 / 478	493	679 / 367	343	433 / 265	180	210 / 146
Node 100	Red Deer River above Fallentimber Creek	2,616	2,616	N	*Prorated*[3]	2,530	7,720 / 1,550	2,340	6,880 / 1,470	2,080	5,810 / 1,340	1,870	4,950 / 1,230	1,570	3,840 / 1,080	1,250	2,780 / 905	1,130	2,420 / 839	977	1,960 / 745	854	1,620 / 669	681	1,189 / 557	498	791 / 427	345	504 / 309	181	245 / 170
Node 101	Red Deer River below Fallentimber Creek	3,146	3,146	N	*Regionalization*[2]	2,760	9,280 / 1,860	2,530	8,270 / 1,770	2,230	6,990 / 1,610	1,990	5,950 / 1,480	1,660	4,620 / 1,300	1,310	3,340 / 1,090	1,180	2,910 / 1,010	1,010	2,360 / 896	879	1,950 / 805	695	1,430 / 670	504	951 / 514	347	606 / 372	183	295 / 204
Node 102	Red Deer River above Bearberry Creek	3,213	3,213	N	*Regionalization*[2]	2,790	9,480 / 1,900	2,560	8,450 / 1,810	2,260	7,140 / 1,640	2,020	6,080 / 1,510	1,680	4,720 / 1,330	1,330	3,410 / 1,110	1,200	2,970 / 1,030	1,030	2,410 / 915	892	1,990 / 822	706	1,460 / 684	513	971 / 525	353	619 / 380	187	301 / 208
Node 103	Red Deer River below Bearberry Creek	3,451	3,451	N	*Regionalization*[2]	2,920	10,200 / 2,040	2,680	9,080 / 1,940	2,370	7,670 / 1,760	2,120	6,530 / 1,620	1,770	5,070 / 1,430	1,390	3,660 / 1,190	1,260	3,190 / 1,110	1,080	2,590 / 983	941	2,140 / 883	745	1,570 / 735	542	1,040 / 564	374	665 / 408	198	323 / 223
Node 104	Red Deer River above James River	3,586	3,586	N	*Regionalization*[2]	2,990	10,600 / 2,120	2,740	9,440 / 2,020	2,430	7,970 / 1,830	2,170	6,790 / 1,680	1,810	5,270 / 1,490	1,430	3,800 / 1,240	1,290	3,320 / 1,150	1,110	2,690 / 1,020	968	2,220 / 918	767	1,630 / 764	558	1,080 / 586	385	691 / 424	205	336 / 232
Node 105	Red Deer River below James River	4,459	4,459	N	*Regionalization*[2]	3,410	13,200 / 2,640	3,140	11,700 / 2,510	2,790	9,910 / 2,280	2,500	8,440 / 2,090	2,100	6,550 / 1,850	1,670	4,730 / 1,540	1,510	4,130 / 1,430	1,300	3,340 / 1,270	1,140	2,760 / 1,140	905	2,030 / 950	661	1,340 / 729	458	859 / 527	246	418 / 288
05CB911 / Node 201	Red Deer River at Garrington Bridge (AEP Station No. 05CB911)	4,699	4,699	N	*Regionalization*[2,4]	3,500	13,900 / 2,780	3,230	12,300 / 2,650	2,870	10,400 / 2,400	2,580	8,890 / 2,200	2,170	6,900 / 1,950	1,720	4,980 / 1,620	1,560	4,350 / 1,510	1,350	3,520 / 1,340	1,180	2,910 / 1,200	937	2,140 / 1,000	685	1,410 / 768	476	905 / 555	248	384 / 272
Node 106	Red Deer River above Raven River	4,777	4,777	N	*Regionalization*[2,4]	3,550	14,100 / 2,830	3,280	12,500 / 2,690	2,910	10,600 / 2,440	2,620	9,040 / 2,240	2,200	7,010 / 1,980	1,750	5,060 / 1,650	1,590	4,420 / 1,530	1,370	3,580 / 1,360	1,200	2,960 / 1,220	953	2,180 / 1,020	698	1,430 / 781	484	920 / 564	248	427 / 293
Node 107	Red Deer River upstream of Gleniffer Lake	5,629	5,583	NZ	3P(MLH)	3,710	7,850 / 2,470	3,430	7,040 / 2,300	3,060	6,020 / 2,090	2,750	5,230 / 1,910	2,320	4,170 / 1,630	1,850	3,050 / 1,340	1,680	2,680 / 1,230	1,450	2,200 / 1,090	1,270	1,850 / 964	1,010	1,380 / 782	733	936 / 583	503	603 / 411	254	293 / 214
Node 108	Red Deer River downstream of Dickson Dam	5,629	5,583	NZ	3P(MLH)	3,710	7,850 / 2,470	3,430	7,040 / 2,300	3,060	6,020 / 2,090	2,750	5,230 / 1,910	2,320	4,170 / 1,630	1,850	3,050 / 1,340	1,680	2,680 / 1,230	1,450	2,200 / 1,090	1,270	1,850 / 964	1,010	1,380 / 782	733	936 / 583	503	603 / 411	254	293 / 214
Node 109	Red Deer River Downstream of Little Red Deer River Confluence	8,207	8,022	NZ	3P(MLH)	4,280	10,900 / 2,950	3,960	9,710 / 2,760	3,540	8,210 / 2,490	3,190	7,050 / 2,280	2,690	5,500 / 1,950	2,150	3,980 / 1,600	1,950	3,450 / 1,460	1,690	2,810 / 1,290	1,480	2,320 / 1,140	1,180	1,690 / 928	858	1,110 / 695	590	704 / 484	299	341 / 243
Node 110	Red Deer River Downstream of Medicine River	10,980	10,696	NZ	3P(MLH)	4,350	7,860 / 2,890	4,050	7,150 / 2,720	3,640	6,250 / 2,500	3,300	5,530 / 2,310	2,820	4,490 / 2,020	2,290	3,410 / 1,690	2,090	3,030 / 1,560	1,820	2,550 / 1,390	1,610	2,190 / 1,250	1,300	1,690 / 1,040	965	1,190 / 794	678	796 / 569	356	412 / 300
Node 111	Red Deer River upstream of Red Deer	11,524	10,966	NZ	3P(MLH)	4,090	7,160 / 2,780	3,800	6,520 / 2,610	3,420	5,700 / 2,400	3,110	5,050 / 2,220	2,660	4,130 / 1,960	2,160	3,170 / 1,630	1,970	2,830 / 1,510	1,720	2,400 / 1,340	1,520	2,050 / 1,200	1,230	1,580 / 989	917	1,120 / 755	647	757 / 545	342	395 / 290
05CC002 / Node 202	Red Deer River at Red Deer (WSC Station No. 05CC002)	11,609	11,052	NZ	3P(MLH)	4,240	7,140 / 2,810	3,940	6,520 / 2,650	3,550	5,710 / 2,440	3,230	5,090 / 2,260	2,760	4,190 / 1,990	2,250	3,230 / 1,670	2,050	2,880 / 1,560	1,790	2,440 / 1,390	1,580	2,090 / 1,250	1,280	1,620 / 1,030	959	1,160 / 788	677	790 / 572	359	416 / 308
Node 112	Red Deer River below Waskasoo Creek	12,096	11,302	NZ	3P(MLH)	4,250	7,170 / 2,810	3,950	6,560 / 2,660	3,560	5,760 / 2,440	3,230	5,110 / 2,260	2,760	4,200 / 2,000	2,240	3,240 / 1,680	2,050	2,880 / 1,560	1,790	2,440 / 1,390	1,580	2,090 / 1,250	1,280	1,620 / 1,030	953	1,150 / 785	672	782 / 568	356	413 / 305
Node 113	Red Deer River above Blindman River	12,096	11,302	NZ	3P(MLH)	4,250	7,170 / 2,810	3,950	6,560 / 2,660	3,560	5,760 / 2,440	3,230	5,110 / 2,260	2,760	4,200 / 2,000	2,240	3,240 / 1,680	2,050	2,880 / 1,560	1,790	2,440 / 1,390	1,580	2,090 / 1,250	1,280	1,620 / 1,030	953	1,150 / 785	672	782 / 568	356	413 / 305

Table 6.1: Final Flood Frequency Estimates - Natural and Naturalized Flows - Adjusted

WSC Station ID / Node ID	WSC Station Name or Location of Interest	Gross Drainage Area (km²)	Effective Drainage Area (km²)	Flow Type[1]	Distribution	Recommended Instantaneous Flood Flows\ (m³/s)																							
						1000-yr		750-yr		500-yr		350-yr		200-yr		100-yr		75-yr		50-yr		35-yr		20-yr		10-yr		5-yr		2-yr	
						Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower
Node 114	Red Deer River below Blindman River	14,010	13,336	NZ	3P(MLH)	4,640	7,790 / 2,890	4,310	7,100 / 2,740	3,880	6,190 / 2,540	3,520	5,490 / 2,360	3,000	4,500 / 2,080	2,430	3,450 / 1,770	2,220	3,070 / 1,640	1,940	2,590 / 1,480	1,710	2,230 / 1,340	1,380	1,720 / 1,120	1,030	1,220 / 855	722	834 / 613	382	450 / 323
Node 115	Red Deer River at Highway 11	14,128	13,454	NZ	3P(MLH)	4,600	7,980 / 2,880	4,270	7,280 / 2,720	3,830	6,350 / 2,510	3,480	5,590 / 2,320	2,960	4,560 / 2,060	2,400	3,480 / 1,740	2,180	3,100 / 1,620	1,900	2,620 / 1,460	1,680	2,220 / 1,320	1,350	1,700 / 1,100	1,000	1,200 / 839	706	815 / 601	374	441 / 316
RED RIVER TRIBUTARIES																													
05CA012 / Node 301	Fallentimber Creek near Sundre (WSC Station No. 05CA012)	489	489	N	LP3(moment)	911	3,030 / 222	820	2,550 / 214	705	2,000 / 201	615	1,610 / 190	492	1,160 / 169	367	763 / 147	323	629 / 138	268	483 / 127	226	382 / 115	169	272 / 96	113	170 / 71.8	70.5	100 / 48	29.5	41.8 / 21.1
05CA011 / Node 302	Bearberry Creek near Sundre (WSC Station No. 05CA011)	238	238	N	EV2	550	1,130 / 117	490	974 / 113	416	796 / 108	360	663 / 104	286	498 / 95	214	351 / 85	189	304 / 80.6	158	248 / 75.4	135	207 / 69.8	104	154 / 61.1	73.3	105 / 49.5	49.2	68.9 / 36.5	23.6	32.9 / 18
05CA002 / Node 303	James River near Sundre (WSC Station No. 05CA002)	821	821	N	LP3(moment)	1,300	3,980 / 430	1,180	3,410 / 413	1,030	2,710 / 384	903	2,210 / 361	735	1,600 / 325	561	1,080 / 277	499	912 / 259	420	709 / 235	358	571 / 211	274	409 / 175	189	262 / 131	122	165 / 88.7	54.9	74 / 41.1
05CB001 / Node 304	Little Red Deer River near the Mouth (WSC Station No. 05CB001)	2,580	2,439	N	LP3(moment)	871	1,830 / 426	810	1,620 / 413	728	1,390 / 390	661	1,190 / 369	563	950 / 336	455	705 / 292	414	619 / 273	360	515 / 247	316	434 / 224	252	334 / 186	184	234 / 138	125	160 / 93.8	58.6	78.5 / 44
05CC007 / Node 305	Medicine River near Eckville (WSC Station No. 05CC007)	1,920	1,857	N	3P(MLH)	503	855 / 328	475	790 / 315	437	708 / 294	405	640 / 277	358	541 / 251	304	436 / 218	282	395 / 205	253	343 / 187	229	301 / 171	193	243 / 147	151	181 / 118	111	133 / 89.9	61.5	75.7 / 49.1
Node 306	Medicine River at the Mouth	2,773	2,674	N	*Prorated*[3]	714	1,230 / 472	673	1,140 / 454	618	1,020 / 423	571	921 / 399	503	779 / 361	424	628 / 314	394	569 / 295	353	494 / 269	318	433 / 246	267	350 / 212	209	261 / 170	156	191 / 129	87.8	109 / 70.7
05CC011 / Node 307	Waskasoo Creek at Red Deer (WSC Station No. 05CC011)	487	250	N	LP3(moment)	107	264 / 39.9	99	231 / 38.5	88.7	192 / 36.7	80.2	161 / 35.1	67.7	122 / 31.9	53.9	87.3 / 27.9	48.7	75.3 / 26.4	41.8	61.7 / 24.2	36.3	51.5 / 21.7	28.3	38.9 / 17.6	19.8	27 / 12.4	12.7	18.3 / 7.91	5.16	8.05 / 3.14
Node 308	Waskasoo Creek above Piper Creek	326	166	N	*Prorated*[3]	72	175 / 26.5	67	154 / 25.6	60.2	128 / 24.4	54.6	107 / 23.3	46.3	81.1 / 21.2	37.1	58 / 18.5	33.5	50.1 / 17.5	28.9	41 / 16.1	25.1	34.2 / 14.4	19.6	25.9 / 11.7	13.7	17.9 / 8.24	8.71	12.2 / 5.26	3.47	5.35 / 2.09
Node 309	Waskasoo Creek below Highway 42	243	142	N	*Prorated*[3]	61.8	149 / 22.6	57.5	131 / 21.9	51.8	109 / 20.8	47	91.3 / 19.9	40	69.2 / 18.1	32.1	49.5 / 15.8	29	42.8 / 14.9	25	35 / 13.7	21.7	29.2 / 12.3	17	22.1 / 9.99	11.9	15.3 / 7.03	7.54	10.4 / 4.49	2.97	4.57 / 1.78
05CC001/ Node 313	Blindman River near Blackfalds	1795.9	1459.1	N	3P(MLH)	739	2100 / 410	685	1870 / 380	612	1590 / 350	553	1370 / 330	468	1050 / 290	375	750 / 240	341	650 / 220	295	530 / 199	258	440 / 180	206	320 / 150	150	210 / 110	102	130 / 80.4	50.4	63.4 / 38.7
WASKASOO CREEK TRIBUTARIES																													
Node 310	Piper Creek above Waskasoo Creek	156	82	N	*Prorated*[3]	36.3	86.3 / 13	33.9	75.5 / 12.6	30.7	62.7 / 12	28	52.6 / 11.5	23.9	39.9 / 10.4	19.3	28.5 / 9.12	17.5	24.6 / 8.63	15.2	20.2 / 7.91	13.2	16.8 / 7.09	10.3	12.7 / 5.75	7.21	8.82 / 4.05	4.55	5.98 / 2.58	1.73	2.63 / 1.03
Node 311	Piper Creek below Highway 595	120	73	N	*Prorated*[3]	32.8	77.8 / 11.7	30.6	68 / 11.3	27.7	56.3 / 10.8	25.3	47.3 / 10.3	21.7	35.9 / 9.33	17.5	25.6 / 8.22	15.9	22.1 / 7.78	13.8	18.2 / 7.11	12	15.1 / 6.36	9.39	11.4 / 5.17	6.55	7.91 / 3.64	4.13	5.38 / 2.32	1.56	2.37 / 0.927
Node 312	Piper Creek below Township Road 374	81	59	N	*Prorated*[3]	26.4	62.3 / 9.37	24.7	54.2 / 9.03	22.4	45 / 8.65	20.5	37.8 / 8.22	17.6	28.7 / 7.46	14.3	20.5 / 6.56	13	17.7 / 6.23	11.2	14.5 / 5.7	9.79	12.1 / 5.09	7.68	9.13 / 4.14	5.36	6.32 / 2.91	3.37	4.3 / 1.85	1.26	1.9 / 0.742

Note:

1) Flow Type: N: Natural; NZ: Naturalized Flows.
2) Regionalization: Instantaneous flood flows were derived based on regional analysis.
3) Prorated: Instantaneous flood flows were estimated by applying ratio between effective drainage area at the node in interest and node upstream or downstream of the node in interest using regional area power factor.
4) 2-year flood adjusted based on interpolation of values from upstream and downstream nodes.

Table 6.2: Final Flood Frequency Estimates - Regulated Flows

WSC Station ID / Node ID	WSC Station Name or Location of Interest	Gross Drainage Area (km²)	Effective Drainage Area (km²)	Flow Type[1]	Recommended Instantaneous Flood Flows\ (m³/s)																							
					1000-yr		750-yr		500-yr		350-yr		200-yr		100-yr		75-yr		50-yr		35-yr		20-yr		10-yr		5-yr		2-yr	
					Flood Est.	Upper Lower	Flood Est.	Upper Lower	Flood Est.	Upper Lower	Flood Est.	Upper Lower	Flood Est.	Upper Lower	Flood Est.	Upper Lower	Flood Est.	Upper Lower	Flood Est.	Upper Lower	Flood Est.	Upper Lower	Flood Est.	Upper Lower	Flood Est.	Upper Lower	Flood Est.	Upper Lower	Flood Est.	Upper Lower
RED DEER RIVER																												
Node 108	Red Deer River downstream of Dickson Dam	5629	5,583	R	3,250	12,908 2,591	2,920	11,128 2,395	2,470	8,997 2,071	2,250	7,763 1,924	1,830	5,831 1,647	1,310	3,788 1,235	1,160	3,225 1,116	966	2,524 959	811	2,000 825	696	898 553	512	625 420	355	418 297	185	218 157
Node 109	Red Deer River Downstream of Little Red Deer River Confluence	8207	8,022	R	4,110	8,696 2,736	3,700	7,594 2,481	3,180	6,256 2,172	2,900	5,515 2,014	2,390	4,296 1,679	1,760	2,902 1,275	1,570	2,505 1,149	1,330	2,018 1,000	1,130	1,646 858	676	1,290 795	534	898 603	402	601 427	234	313 226
Node 110	Red Deer River Downstream of Medicine River	10980	10,696	R	4,420	9,352 2,943	4,000	8,210 2,682	3,460	6,807 2,363	3,150	5,991 2,188	2,620	4,709 1,841	1,950	3,215 1,412	1,750	2,792 1,281	1,480	2,246 1,113	1,270	1,850 964	768	1,720 1,060	619	1,200 804	478	801 569	290	417 301
Node 111	Red Deer River upstream of Red Deer	11524	10,966	R	3,810	9,703 2,626	3,500	8,582 2,439	3,100	7,190 2,181	2,830	6,254 2,023	2,390	4,887 1,733	1,820	3,369 1,354	1,630	2,884 1,220	1,390	2,311 1,061	1,200	1,881 924	720	1,760 1,090	586	1,230 824	457	821 583	282	428 309
05CC002. / Node 202	Red Deer River at Red Deer (WSC Station No. 05CC002)	11609	11,052	R	3,810	6,884 2,531	3,500	6,179 2,351	3,100	5,323 2,129	2,830	4,742 1,981	2,390	3,805 1,712	1,820	2,710 1,343	1,630	2,363 1,217	1,390	1,948 1,062	1,200	1,632 932	720	1,770 1,100	586	1,240 830	457	827 588	282	431 311
Node 112	Red Deer River below Waskasoo Creek	12096	11,302	R	3,910	6,845 2,658	3,590	6,160 2,466	3,190	5,317 2,239	2,910	4,725 2,077	2,460	3,819 1,813	1,870	2,744 1,411	1,680	2,413 1,288	1,430	1,995 1,114	1,230	1,659 971	721	1,810 1,120	587	1,270 849	458	846 601	283	441 318
Node 113	Red Deer River above Blindman River	12096	11,302	R	3,870	6,517 2,565	3,570	5,908 2,401	3,150	5,067 2,165	2,880	4,538 2,015	2,440	3,704 1,759	1,860	2,670 1,381	1,670	2,346 1,271	1,430	1,949 1,110	1,230	1,627 973	721	1,810 1,120	587	1,270 849	458	846 601	283	441 318
Node 114	Red Deer River below Blindman River	14010	13,336	R	4,440	7,491 2,936	4,130	6,859 2,781	3,630	5,873 2,488	3,310	5,237 2,316	2,810	4,276 2,036	2,180	3,153 1,635	1,980	2,782 1,507	1,720	2,345 1,336	1,490	1,971 1,179	782	2,140 1,320	647	1,500 1,000	512	998 709	320	520 375
Node 115	Red Deer River at Highway 11	14128	13,454	R	4,420	7,457 2,922	4,110	6,826 2,768	3,610	5,841 2,474	3,290	5,205 2,302	2,790	4,246 2,022	2,180	3,153 1,635	1,970	2,768 1,499	1,710	2,331 1,328	1,490	1,971 1,179	770	2,160 1,330	640	1,510 1,010	508	1,010 715	318	525 378

Note:

1) Flow Type: R: Regulated Flows

Signature Page

This report was prepared and reviewed by the undersigned:

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PERMIT TO PRACTICE
GOLDER ASSOCIATES LTD

RM SIGNATURE: _____

RM APEGA ID #: _____

DATE: _____

PERMIT NUMBER: P005122
The Association of Professional Engineers and Geoscientists of Alberta (APEGA)

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APPENDIX A

Data Used in this Study

Table A.1: Results of Statistical Tests of Annual Maximum Instantaneous Floods and Goodness-of-Fit of Probability Distribution Functions - Natural and Naturalized Flows

WSC Station ID / Node ID	RED DEER RIVER																		RED DEER RIVER TRIBUTARIES						RED DEER RIVER TRIBUTARIES
	05CA009 / Node 200	Node 100	Node 101	Node 102	Node 103	Node 104	Node 105	05CB911 / Node 201	Node 106	Node 107	Node 108	Node 109	Node 110	Node 111	05CC002 / Node 202	Node 112	Node 113	Node 114	Node 115	05CA012 / Node 301	05CA011 / Node 302	05CA002 / Node 303	05CB001 / Node 304	05CC007 / Node 305	Node 306	05CC011 / Node 307
WSC Station Name or Location of Interest	Red Deer River below Burnt Timber Creek (WSC Station No. 05CA009)	Red Deer River above Fallentimber Creek[1]	Red Deer River below Fallentimber Creek[1]	Red Deer River above Bearberry Creek[1]	Red Deer River below Bearberry Creek[1]	Red Deer River above James River[1]	Red Deer River below James River[1]	Red Deer River at Garrington Bridge (AEP Station No. 05CB911)[1]	Red Deer River above Raven River[1]	Red Deer River upstream of Glenriffer Lake	Red Deer River downstream of Dickson Dam	Red Deer River Downstream of Little Red Deer River Confluence	Red Deer River Downstream of Medicine River	Red Deer River upstream of Red Deer	Red Deer River at Red Deer (WSC Station No. 05CC002)	Red Deer River below Waskasoo Creek	Red Deer River above Blindman River	Red Deer River below Blindman River	Red Deer River at Highway 11	Fallentimber Creek near Sundre (WSC Station No. 05CA012)	Bearberry Creek near Sundre (WSC Station No. 05CA011)	James River near Sundre (WSC Station No. 05CA002)	Little Red Deer River near the Mouth (WSC Station No. 05CB001)	Medicine River near Eckville (WSC Station No. 05CC007)	Medicine River at the Mouth[2]	Waskasoo Creek at Red Deer (WSC Station No. 05CC011)
Anderson-Darling statistic, A^2 = - N -S																										
3 Parameter Log-normal	0.519	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	0.741	0.741	0.781	0.345	0.369	0.344	0.360	0.360	0.563	0.535	0.190	0.440	0.304	0.686	0.270	*n/a*	0.278
Extreme Value	0.458	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	1.329	1.329	1.455	0.740	0.840	0.720	0.748	0.748	0.720	0.735	0.191	0.308	0.339	0.805	0.403	*n/a*	0.517
Log_Pearson III	0.303	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	0.742	0.742	0.823	0.455	0.486	0.444	0.467	0.467	0.545	0.541	0.160	0.337	0.271	0.660	0.290	*n/a*	0.249
Weibull	1.716	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	1.4	1.4	1.440	0.449	0.766	0.571	0.624	0.624	0.473	0.504	0.717	8.139	14.134	1.039	0.541	*n/a*	0.760
Serial correlation coefficient test for independence																										
S_1	0.151	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	0.147	0.147	0.161	0.132	0.140	0.127	0.128	0.128	0.107	0.127	0.095	-0.117	0.007	0.285	-0.086	*n/a*	-0.146
t	1.211	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	1.503	1.503	1.644	1.337	1.422	1.282	1.299	1.299	1.078	1.283	0.570	-0.709	0.048	2.126	-0.620	*n/a*	-0.797
t(α=0.05)	1.669	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	1.660	1.660	1.660	1.660	1.660	1.660	1.660	1.660	1.660	1.660	1.688	-1.688	1.677	1.675	-1.675	*n/a*	-1.699
t(α=0.01)	2.387	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	2.363	2.363	2.364	2.364	2.364	2.364	2.364	2.364	2.364	2.364	2.434	-2.434	2.407	2.402	-2.400	*n/a*	-2.462
Spearman rank order correlation coefficient test for no-trend																										
r_s	0.040	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	0.009	0.009	0.024	0.035	0.074	0.073	0.083	0.083	0.082	0.093	-0.239	-0.026	-0.149	-0.240	0.038	*n/a*	0.021
t	0.317	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	0.093	0.093	0.245	0.358	0.750	0.741	0.839	0.839	0.828	0.943	-1.495	-0.159	-1.058	-1.782	0.276	*n/a*	0.116
t(α=0.05)	1.998	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	1.983	1.983	1.983	1.983	1.983	1.983	1.983	1.983	1.983	1.983	-2.026	-2.026	-2.010	-2.007	2.006	*n/a*	2.042
t(α=0.01)	2.655	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	2.624	2.624	2.625	2.625	2.625	2.625	2.625	2.625	2.625	2.625	-2.715	-2.715	-2.680	-2.674	2.672	*n/a*	2.750
Mann-Whitney split sample test for homogeneity																										
Size of earlier sample	33	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	53	53	52.000	52	52.000	53	52.000	52	52.000	52	20	20	26	27	28	*n/a*	20
z	-0.321	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	-0.385	-0.385	-0.078	-0.143	-0.530	-0.842	-0.673	-0.673	-0.559	-0.731	-0.871	-0.309	-1.112	-1.687	-0.354	*n/a*	-0.662
z(α=0.05)	-1.645	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	-1.645	-1.645	-1.645	-1.645	-1.645	-1.645	-1.645	-1.645	-1.645	-1.645	-1.645	-1.645	-1.645	-1.645	-1.645	*n/a*	-1.645
z(α=0.01)	-2.326	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	-2.326	-2.326	-2.326	-2.326	-2.326	-2.326	-2.326	-2.326	-2.326	-2.326	-2.326	-2.326	-2.326	-2.326	-2.326	*n/a*	-2.326
Test of general randomness (Runs for above or below the median)																										
Median	156.8	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	232	232	260.606	343	328.538	343	342.913	343	421.658	399	28.2	25.7	54.9	59.6	59.1	*n/a*	5.4
N1(for Q>=Median)	33	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	53	53	52.000	52	52.000	53	52.000	52	52.000	52	20	20	26	27	28	*n/a*	16
N2(for Q<Median)	33	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	52	52	52.000	52	52.000	51	52.000	52	52.000	52	19	19	25	27	27	*n/a*	16
Run_ab	29	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	46	46	42.000	50	46.000	46	46.000	46	50.000	46	17	24	28	18	30	*n/a*	20
z	1.240	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	1.470	1.470	2.168	0.591	1.380	1.376	1.380	1.380	0.591	1.380	1.133	1.141	0.427	2.748	0.411	*n/a*	1.078
z(a=0.05)	1.960	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	1.960	1.960	1.960	1.960	1.960	1.960	1.960	1.960	1.960	1.960	1.960	1.960	1.960	1.960	1.960	*n/a*	*n/a*
z(a=0.01)	2.576	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	*n/a*	2.576	2.576	2.576	2.576	2.576	2.576	2.576	2.576	2.576	2.576	2.576	2.576	2.576	2.576	2.576	*n/a*	*n/a*

Notes:

1) Flood estimates were calculated based on regional analysis
2) Flood estimates were calculated using prorating based on drainage area
3) Selected distribution based on best statistical fit 0.519
4) Criteria for the respective statistical tests were not met 1.960

n/a, statistical test is either not applicable or not available

Table A.2: Results of Statistical Tests of Annual Maximum Instantaneous Floods and Goodness-of-Fit of Probability Distribution Functions - Regulated Flows

WSC Station ID / Node ID	Node 108	Node 109	Node 110	Node 111	05CC002 / Node 202	Node 112	Node 113	Node 114	Node 115
WSC Station Name or Location of Interest	Red Deer River downstream of Dickson Dam	Red Deer River Downstream of Little Red Deer River Confluence	Red Deer River Downstream of Medicine River	Red Deer River upstream of Red Deer	Red Deer River at Red Deer (WSC Station No. 05CC002)	Red Deer River below Waskasoo Creek	Red Deer River above Blindman River	Red Deer River below Blindman River	Red Deer River at Highway 11
Anderson-Darling statistic, A^2 = - N -S									
3 Parameter Log-normal	2.499	0.950	1.149	1.535	1.535	1.549	1.549	0.983	1.005
Extreme Value	3.273	1.168	1.096	1.393	1.393	1.402	1.402	0.987	1.025
Log_Pearson III	2.754	1.093	1.232	1.539	1.539	1.544	1.544	1.114	1.158
Weilbull	2.7	14.937	21.927	18.963	18.963	19.746	19.746	3.550	2.070
Serial correlation coefficient test for independence									
S_1	0.146	0.201	0.201	0.215	0.215	0.216	0.216	0.184	0.183
t	1.488	2.068	2.071	2.228	2.228	2.234	2.234	1.892	1.879
t(α=0.05)	1.660	1.660	1.660	1.660	1.660	1.660	1.660	1.660	1.660
t(α=0.01)	2.363	2.363	2.363	2.363	2.363	2.363	2.363	2.363	2.363
Spearman rank order correlation coefficient test for no-trend									
r_s	0.036	-0.009	0.003	-0.003	-0.003	-0.011	-0.011	-0.046	-0.035
t	0.369	-0.087	0.029	-0.033	-0.033	-0.108	-0.108	-0.470	-0.358
t(α=0.05)	1.983	-1.983	1.983	-1.983	-1.983	-1.983	-1.983	-1.983	-1.983
t(α=0.01)	2.624	-2.624	2.624	-2.624	-2.624	-2.624	-2.624	-2.624	-2.624
Mann-Whitney split sample test for homogeneity									
Size of earlier sample	53	53.000	53	53.000	53	53.000	53	53.000	53
z	-0.329	-0.711	-0.705	-0.821	-0.821	-0.808	-0.808	-1.301	-1.186
z(α=0.05)	-1.645	-1.645	-1.645	-1.645	-1.645	-1.645	-1.645	-1.645	-1.645
z(α=0.01)	-2.326	-2.326	-2.326	-2.326	-2.326	-2.326	-2.326	-2.326	-2.326
Test of general randomness (Runs for above or below the median)									
Median	174	235.860	314	297.613	298	301.243	301	331.588	330
N1(for Q>=Median)	53	53.000	53	53.000	53	53.000	53	53.000	53
N2(for Q<Median)	52	52.000	52	52.000	52	52.000	52	52.000	52
Run_ab	48	48.000	50	48.000	48	48.000	48	50.000	52
z	1.078	1.078	0.686	1.078	1.078	1.078	1.078	0.686	0.293
z(a=0.05)	1.960	1.960	1.960	1.960	1.960	1.960	1.960	1.960	1.960
z(a=0.01)	2.576	2.576	2.576	2.576	2.576	2.576	2.576	2.576	2.576

Notes:

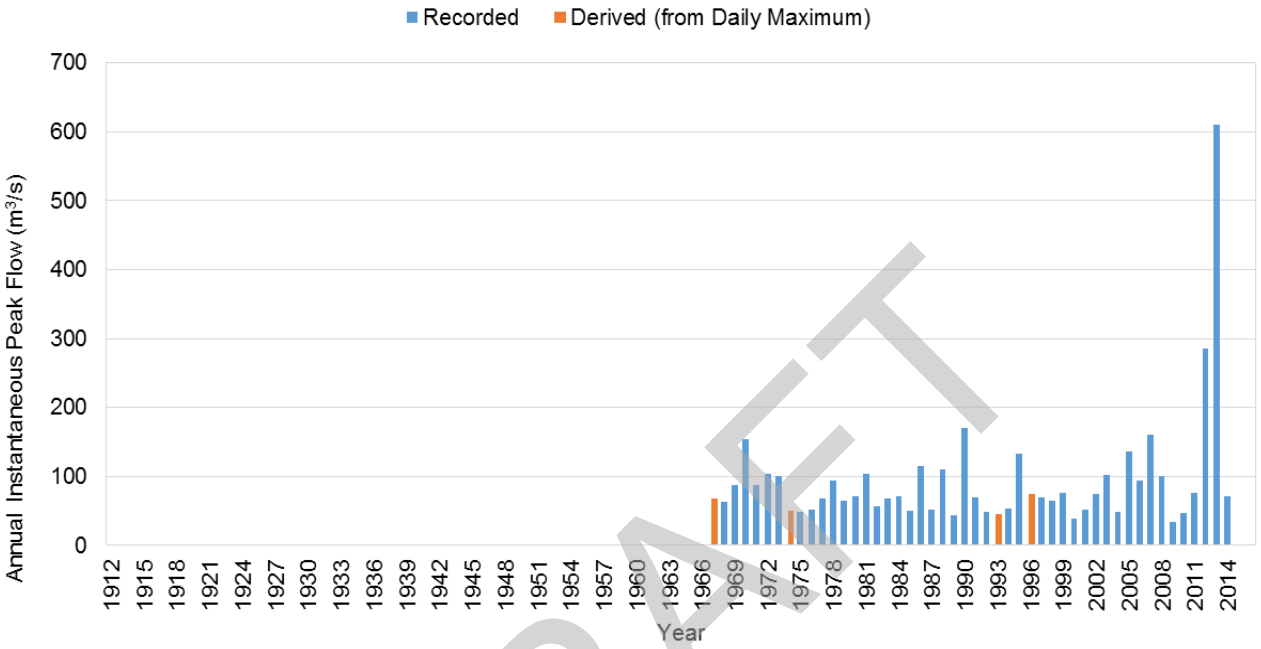
1) Selected distribution based on best statistical fit 2.499

2) Criteria for the respective statistical tests were not met 1.660

RED DEER RIVER – Recorded and Naturalized

Figure A.1: Node 500 - Red Deer River above Panther River

Annual maximum instantaneous flows were estimated based on the relationship between annual daily maximum flows and annual maximum instantaneous flows at Red Deer River above Panther River (05CA004).



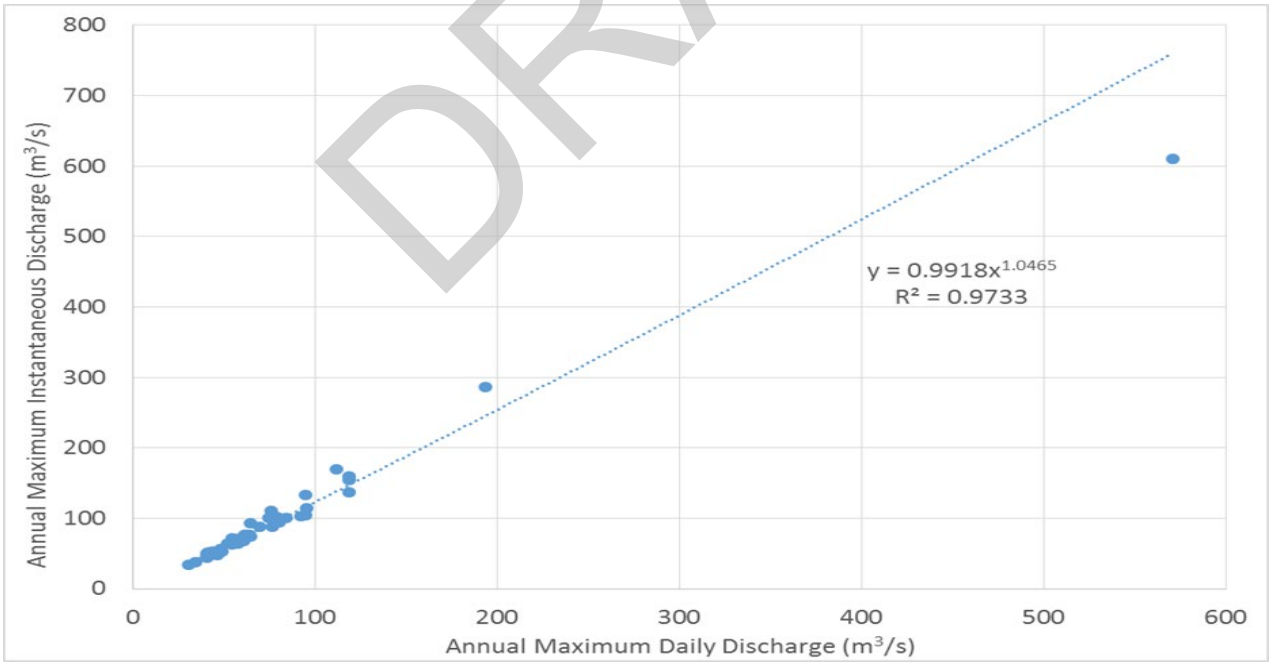
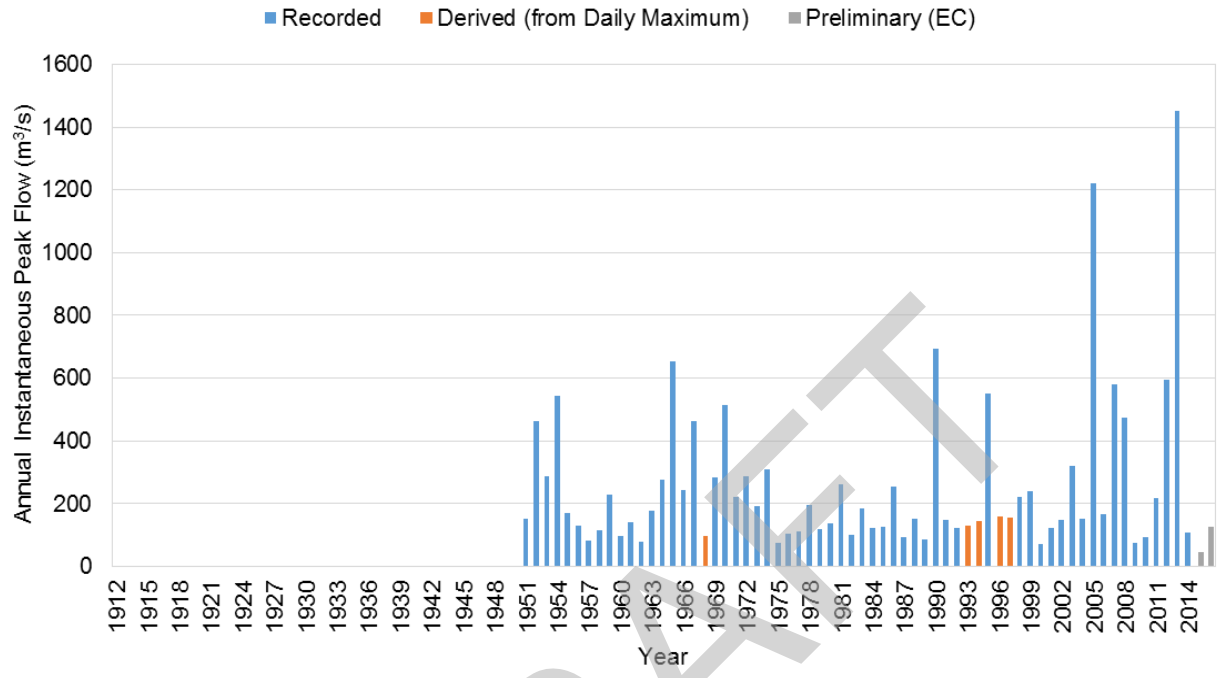


Figure A.2: Node 501, Red Deer River below Burnt Timber Creek

Annual maximum instantaneous flows were estimated based on the relationship between annual daily maximum flows and annual maximum instantaneous flows at Red Deer River near Sundre (05CA001) and Red Deer River below Burnt Timber Creek (05CA009).



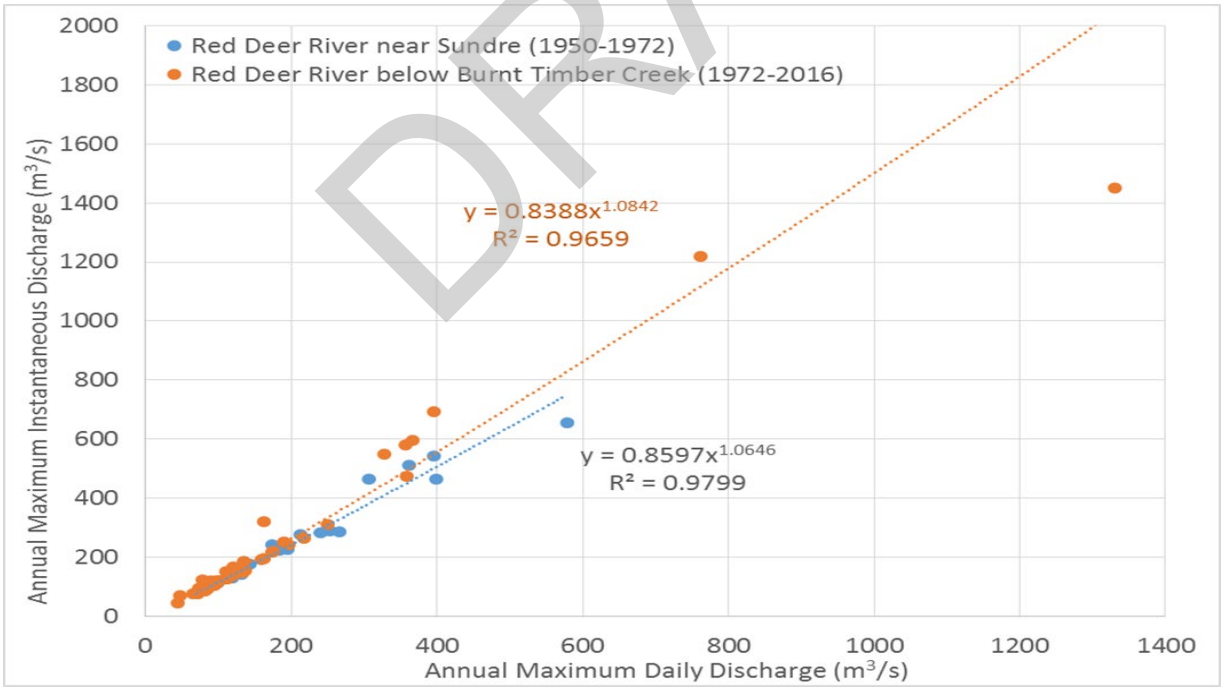
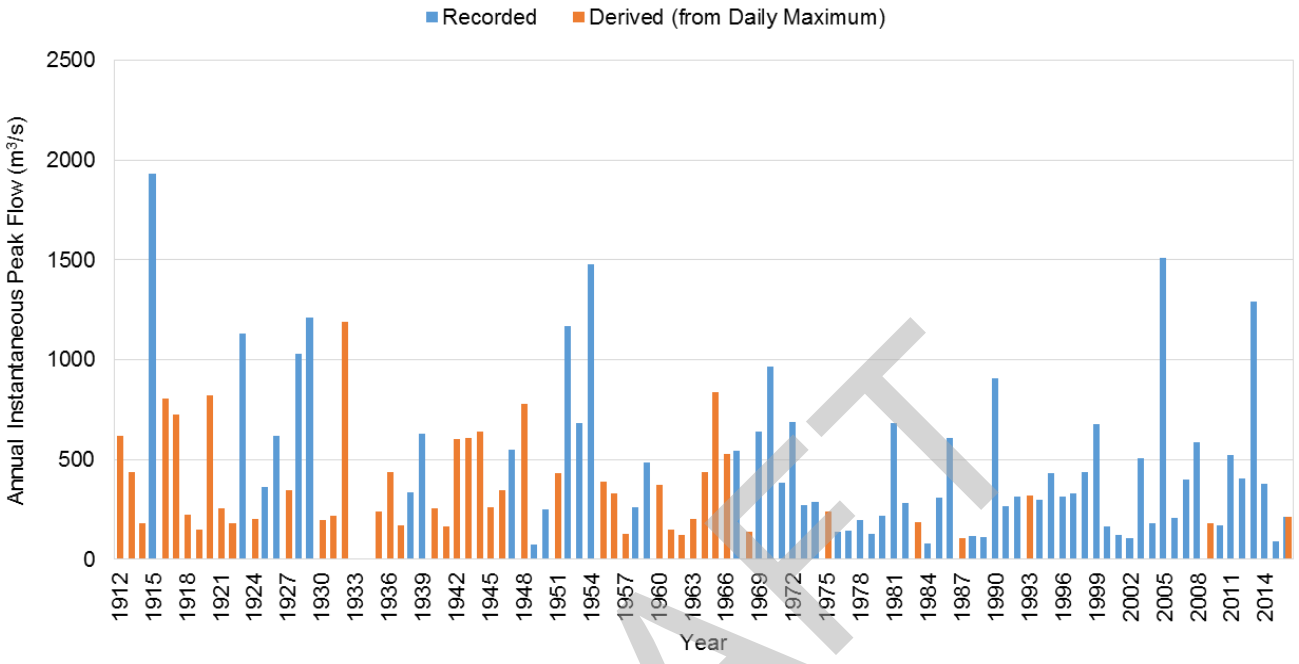


Figure A.3: Node 111, Red Deer River at Red Deer

Annual maximum instantaneous flows were estimated based on the relationship between annual daily maximum flows and annual maximum instantaneous flows at Red Deer River at Red Deer (05CC002).



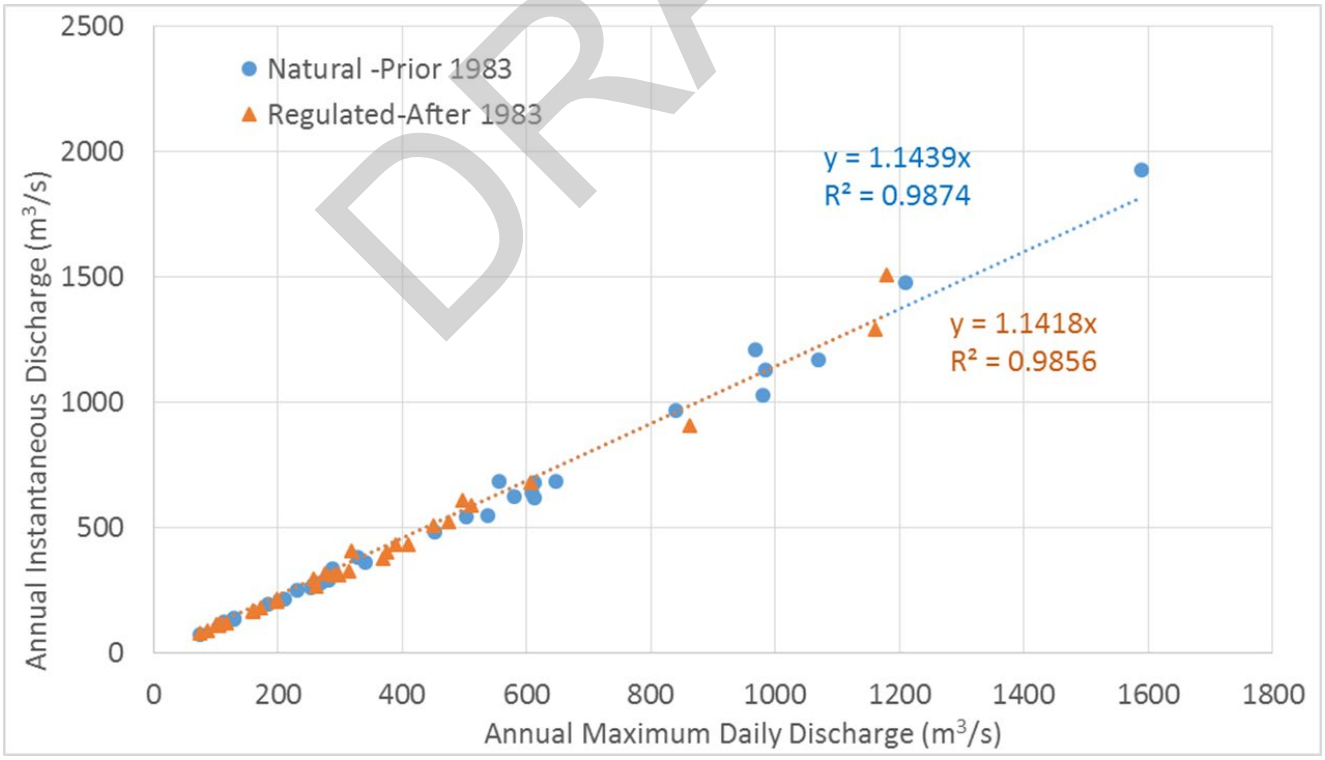
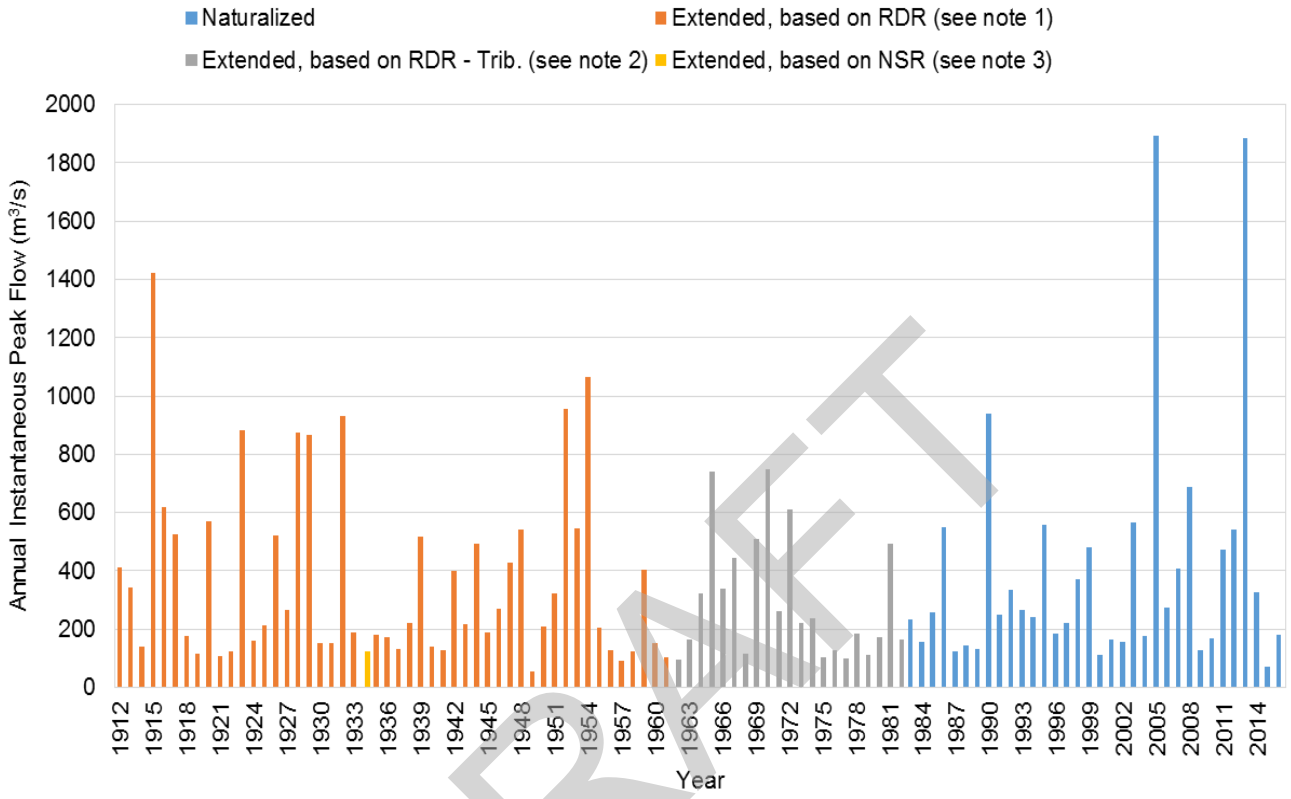


Figure A.4: Node 107, Red Deer River above Gleniffer Reservoir

Annual maximum instantaneous flows were estimated based on the relationship between annual daily maximum flows and annual maximum instantaneous flows at Red Deer River at Red Deer (05CC002).



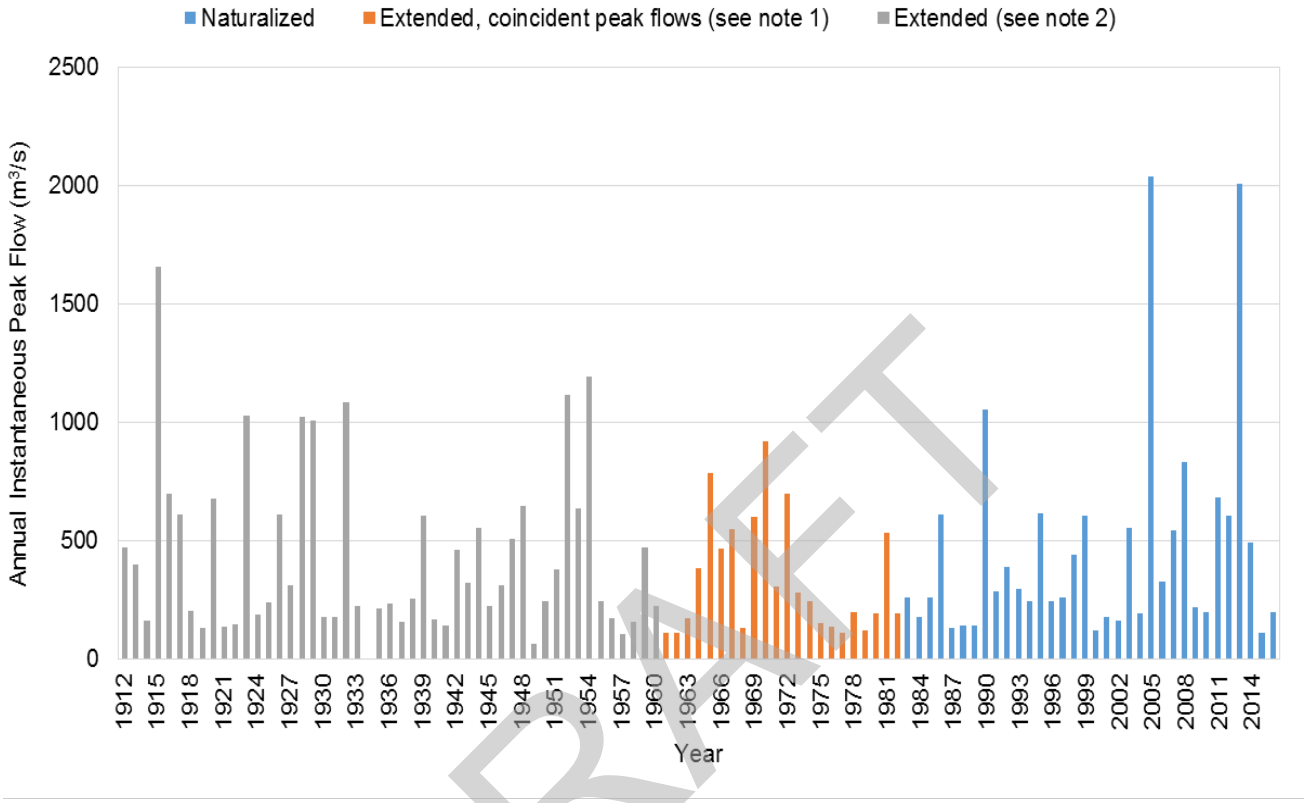
Note 1: Extended based on Red Deer River at Red Deer (05CC002) and its tributaries, covers period of record from 1912 - 1933 and 1935 to 1982

Note 2: Extended based on Red Deer River at Red Deer (05CC002) subtracting its tributaries, Little Red Deer River near the Mouth (05CB001) and Medicine River near Eckville (05CC007), covers period of record from 1962 to 1982

Note 3: Extended base on North Saskatchewan River at Rocky Mountain House (05DC001), for year 1934

Figure A.5: Node 108, Red Deer River Downstream of Little Red Deer River Confluence

Annual maximum instantaneous flows were estimated based on the relationship between annual daily maximum flows and annual maximum instantaneous flows at Red Deer River at Red Deer (05CC002) (see Figure A.3).

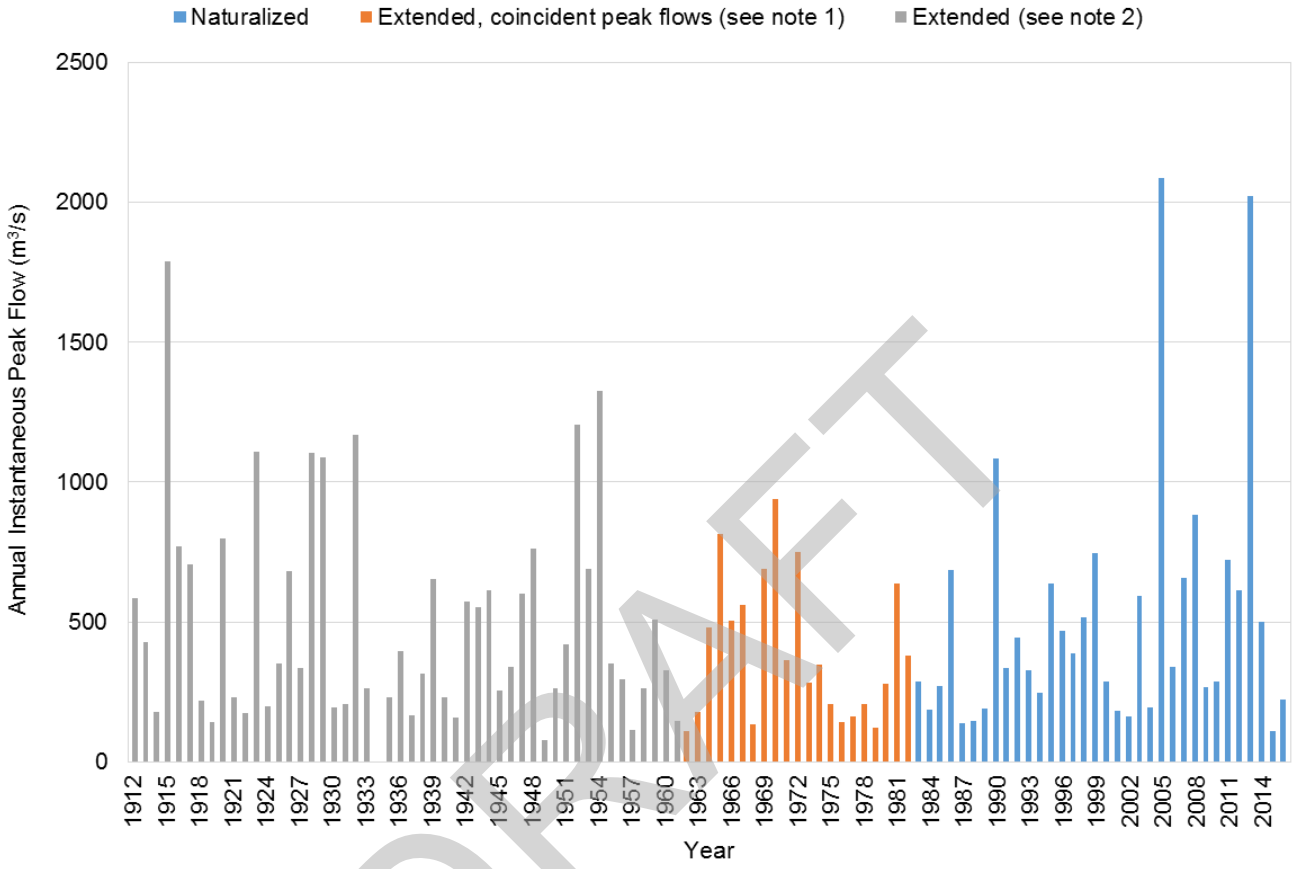


Note 1: Extended by combining Red Deer River above Gleniffer Reservoir (Node 1) and Little Red Deer River near the Mouth (05CB001) assuming coincident peak flows

Note 2: Naturalized flow derived based on relationship established with inflows to Gleniffer Reservoir using naturalized data from 1983 to 2016

Figure A.6: Node 110, Red Deer River Downstream of Medicine River

Annual maximum instantaneous flows were estimated based on the relationship between annual daily maximum flows and annual maximum instantaneous flows at Red Deer River at Red Deer (05CC002) (see Figure A.3).

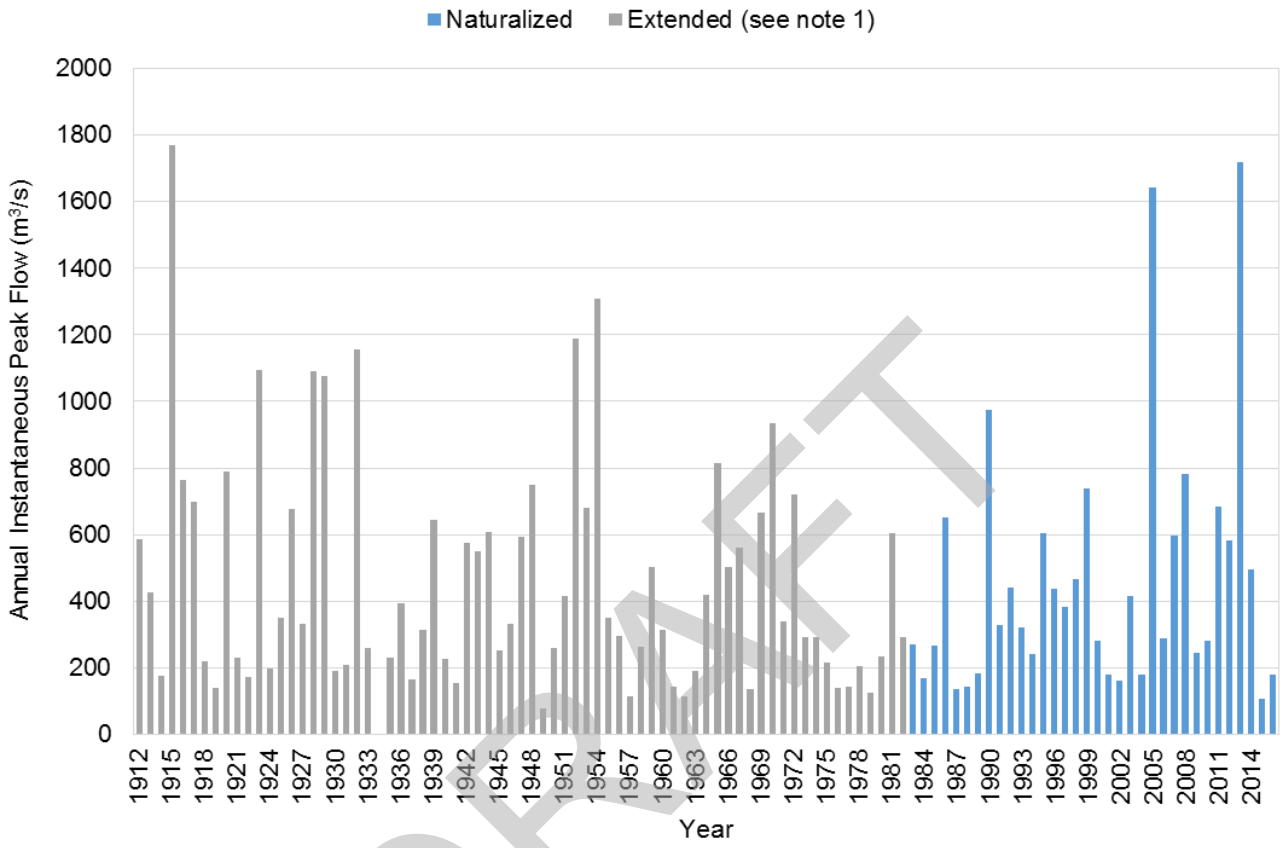


Note 1: Extended by combining Red Deer River Downstream of Little Red Deer River Confluence (Node 2) and Medicine River near Eckville (05CC007) assuming coincident peak flows

Note 2: Naturalized flow derived based on relationship established with flows for Red Deer River at Red Deer using naturalized data from 1983 to 2016

Figure A.7: Node 111, Red Deer River at the City Red Deer

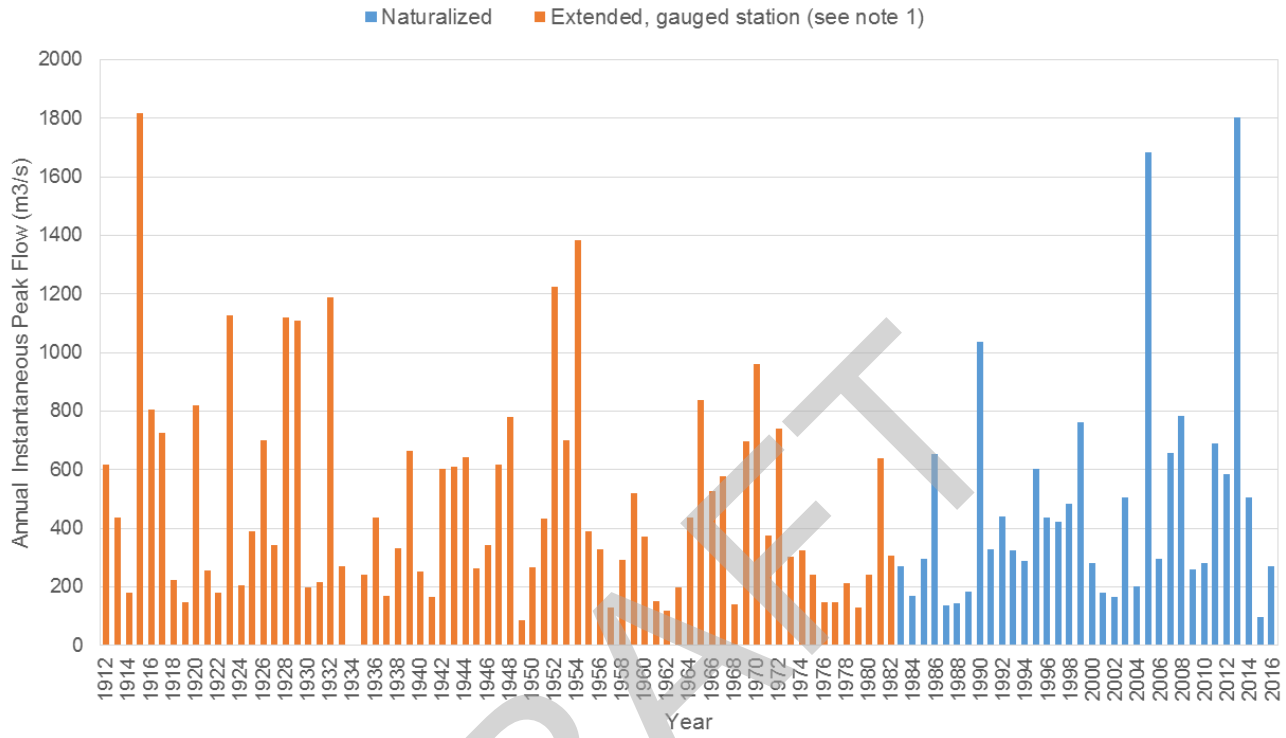
Annual maximum instantaneous flows were estimated based on the relationship between annual daily maximum flows and annual maximum instantaneous flows at Red Deer River at Red Deer (05CC002) (see Figure A.3).



Note 1: Naturalized flow derived based on relationship established with flows for Red Deer River at Red Deer using naturalized data from 1983 to 2016

Figure A.8: 05CC002 / Node 202, Red Deer River at Red Deer

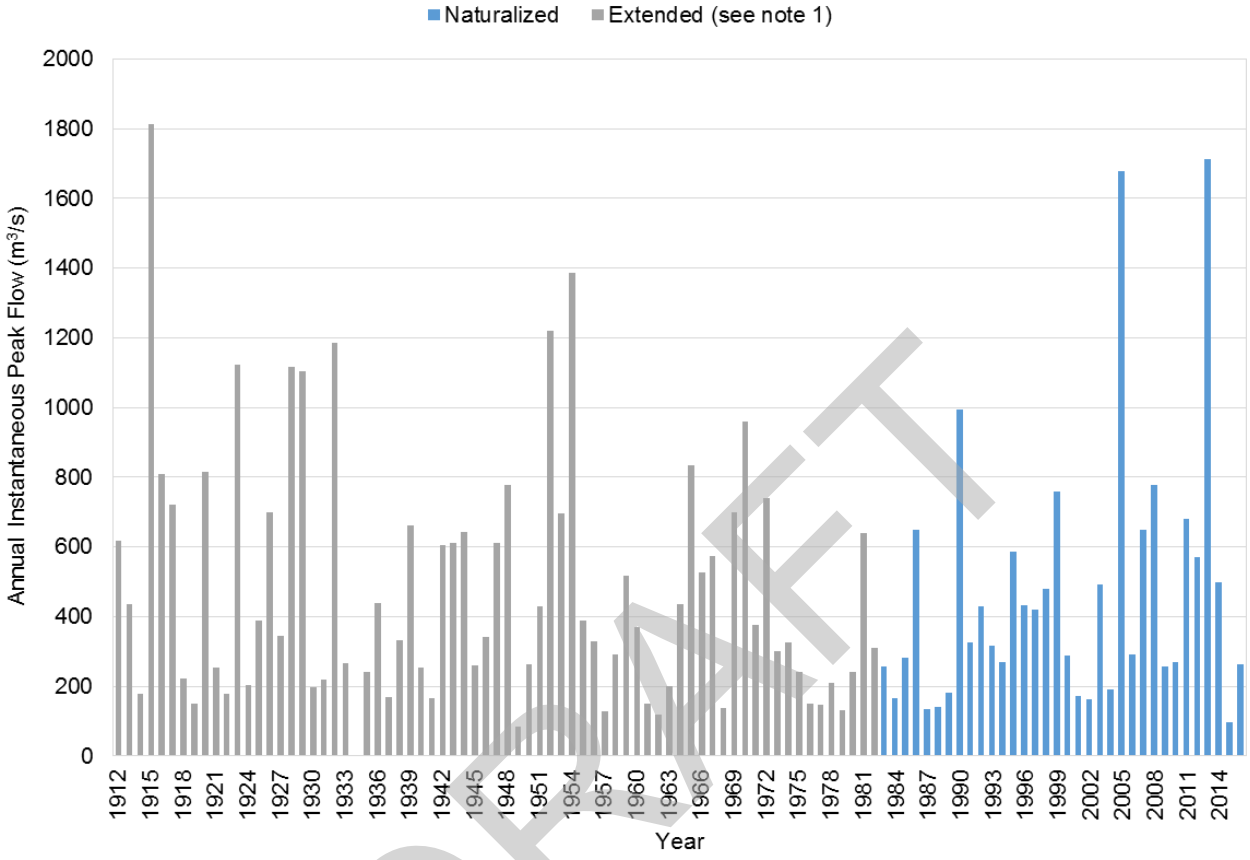
Annual maximum instantaneous flows were estimated based on the relationship between annual daily maximum flows and annual maximum instantaneous flows at Red Deer River at Red Deer (05CC002) (see Figure A.3).



Note 1: Extended based on recorded data at gauged station, Red Deer River at Red Deer (05CC002)

Figure A.9: Node 112, Red Deer River Downstream of Waskasoo Creek Confluence

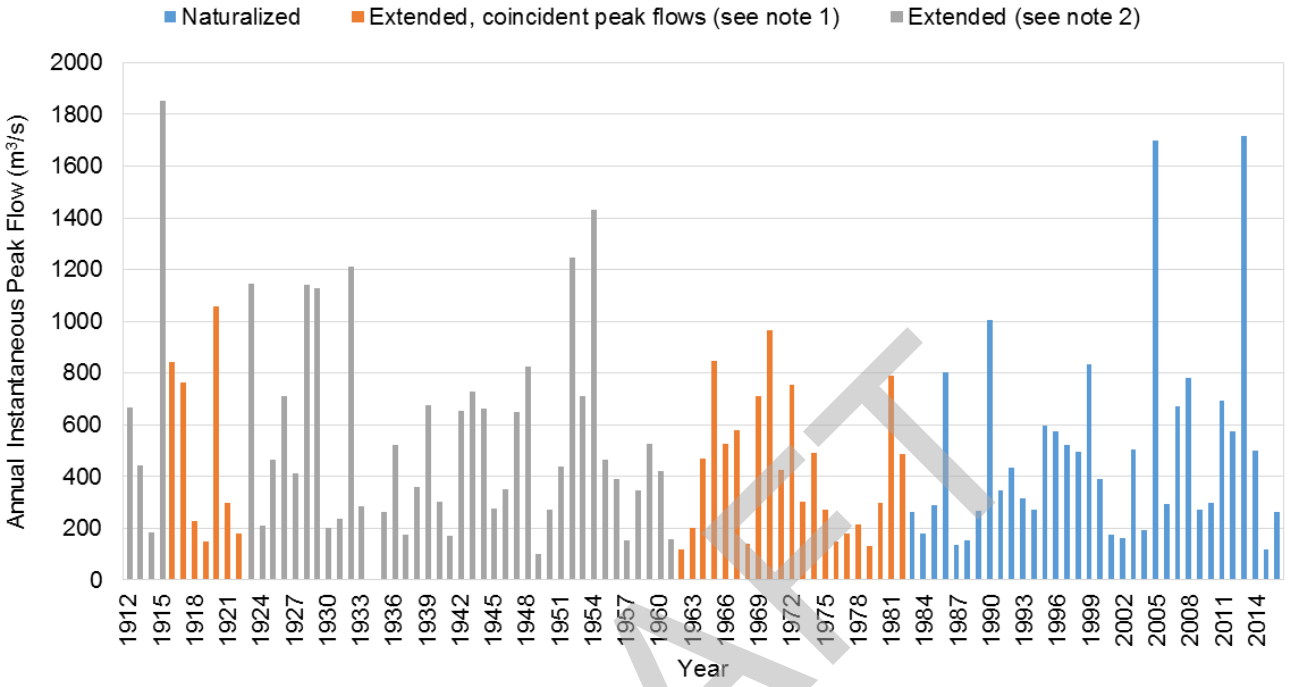
Annual maximum instantaneous flows were estimated based on the relationship between annual daily maximum flows and annual maximum instantaneous flows at Red Deer River at Red Deer (05CC002) (see Figure A.3).



Note 1: Naturalized flow derived based on relationship established with flows for Red Deer River at Red Deer using naturalized data from 1983 to 2016

Figure A.10: Node 114, Red Deer River Downstream of Blindman River Confluence

Annual maximum instantaneous flows were estimated based on the relationship between annual daily maximum flows and annual maximum instantaneous flows at Red Deer River at Red Deer (05CC002) (see Figure A.3).

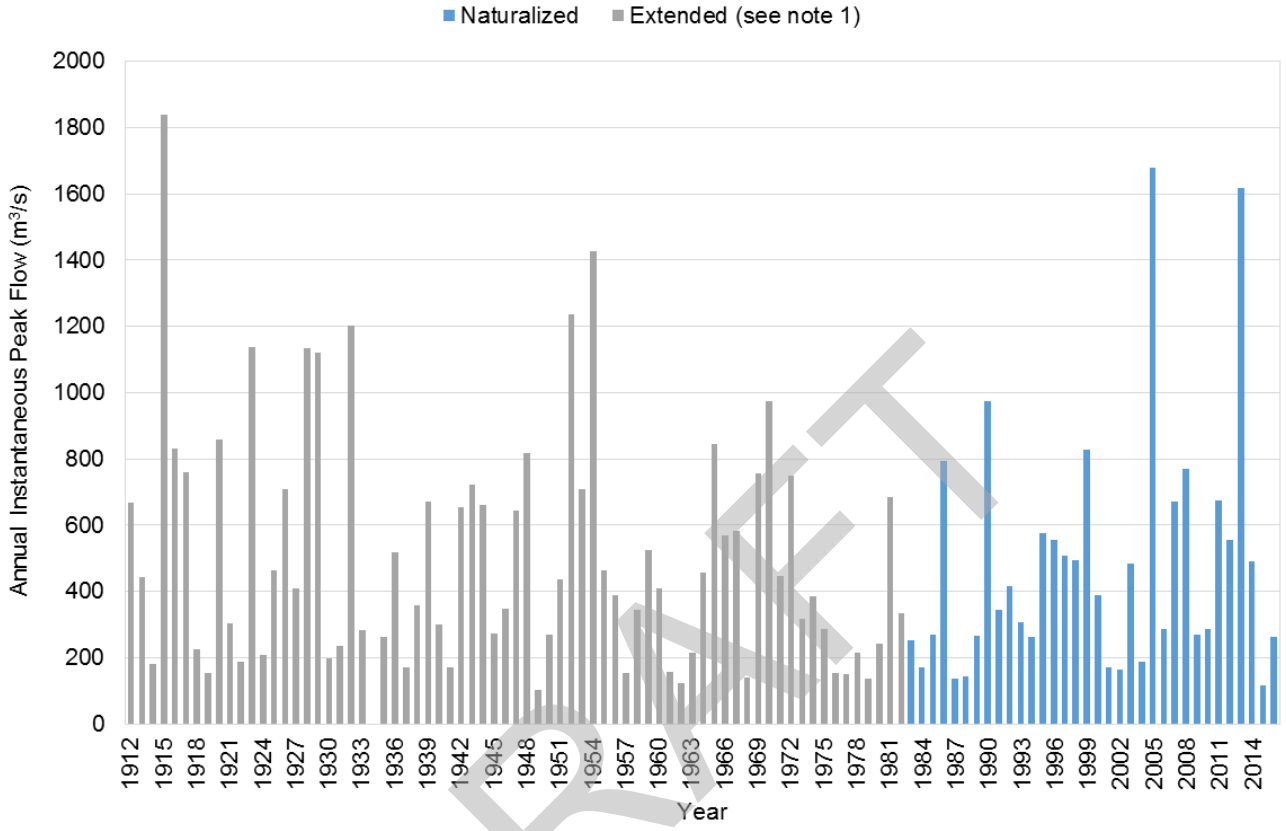


Note 1: Extended by combining Red Deer River at Red Deer (Node 4) and Blindman River near Blackfalds (05CC001) assuming coincident peak flows

Note 2: Naturalized flow derived based on relationship established with flows for Red Deer River at Red Deer using naturalized data from 1983 to 2016

Figure A.11: Node 115, Red Deer River at Highway 11

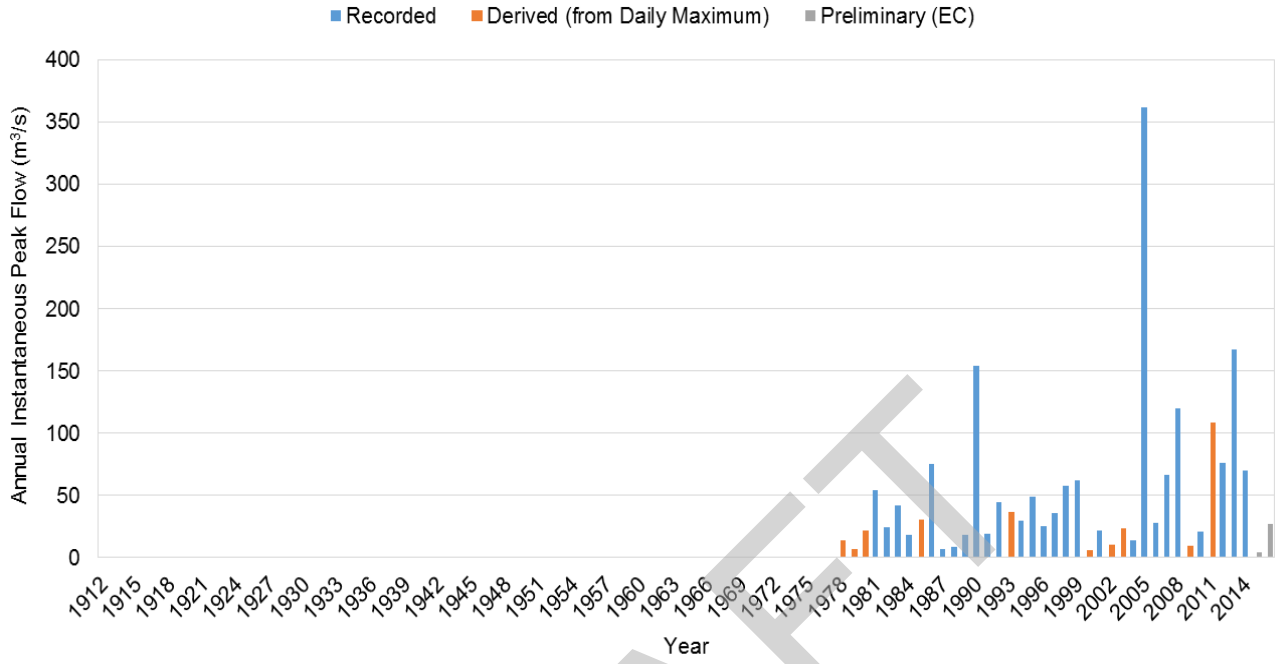
Annual maximum instantaneous flows were estimated based on the relationship between annual daily maximum flows and annual maximum instantaneous flows at Red Deer River at Red Deer (05CC002) (see Figure A.3).



Note 1: Naturalized flow derived based on relationship established with flows for Red Deer River at Red Deer using naturalized data from 1983 to 2016

RED DEER RIVER TRIBUTARIES

Figure A.12: Node 301- 05CA012, Fallentimber Creek near Sundre



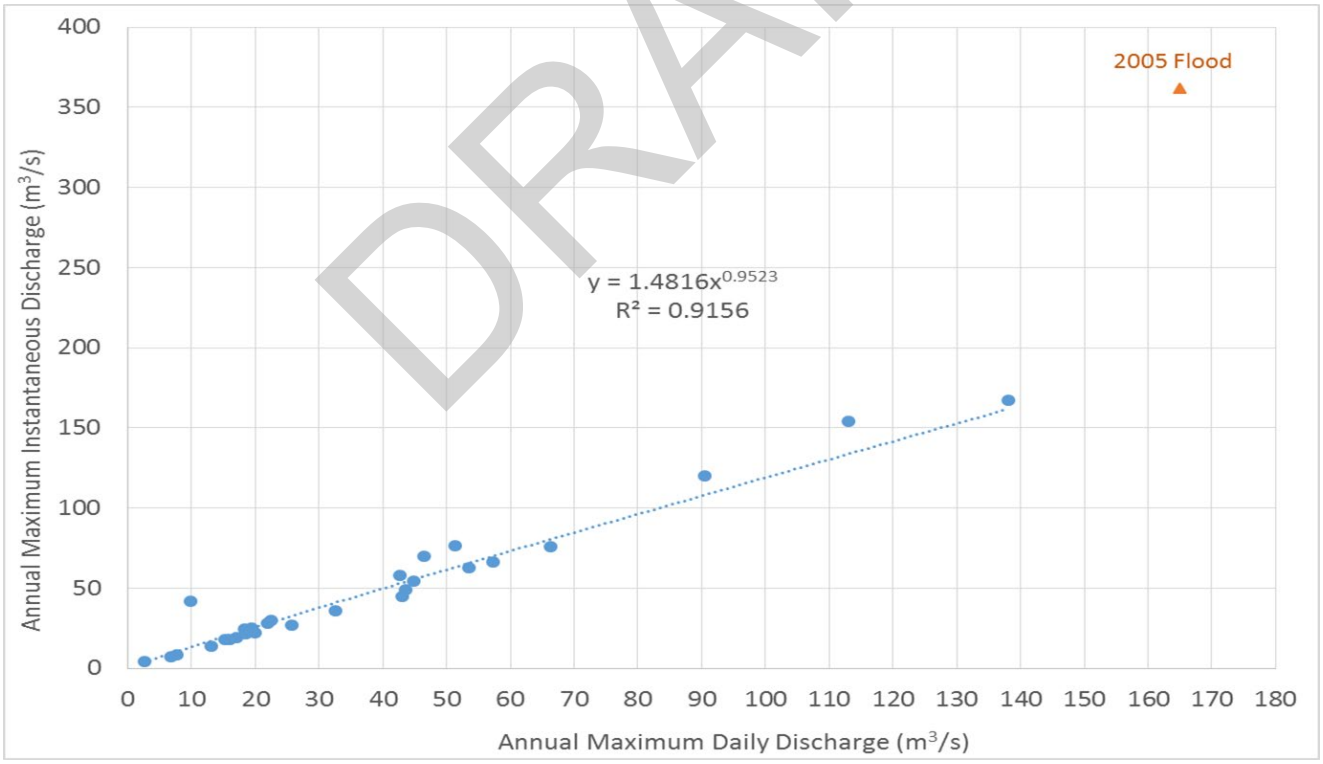
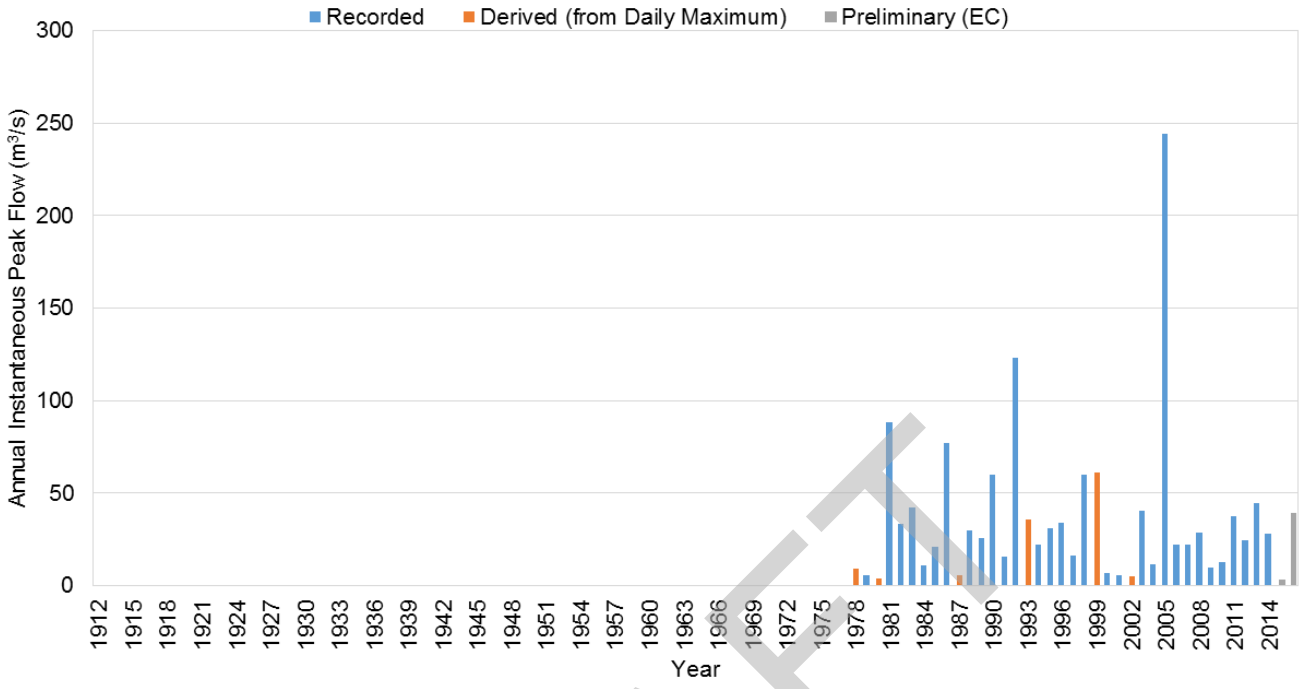


Figure A.13: Node 302 - 05CA011, Bearberry Creek near Sundre



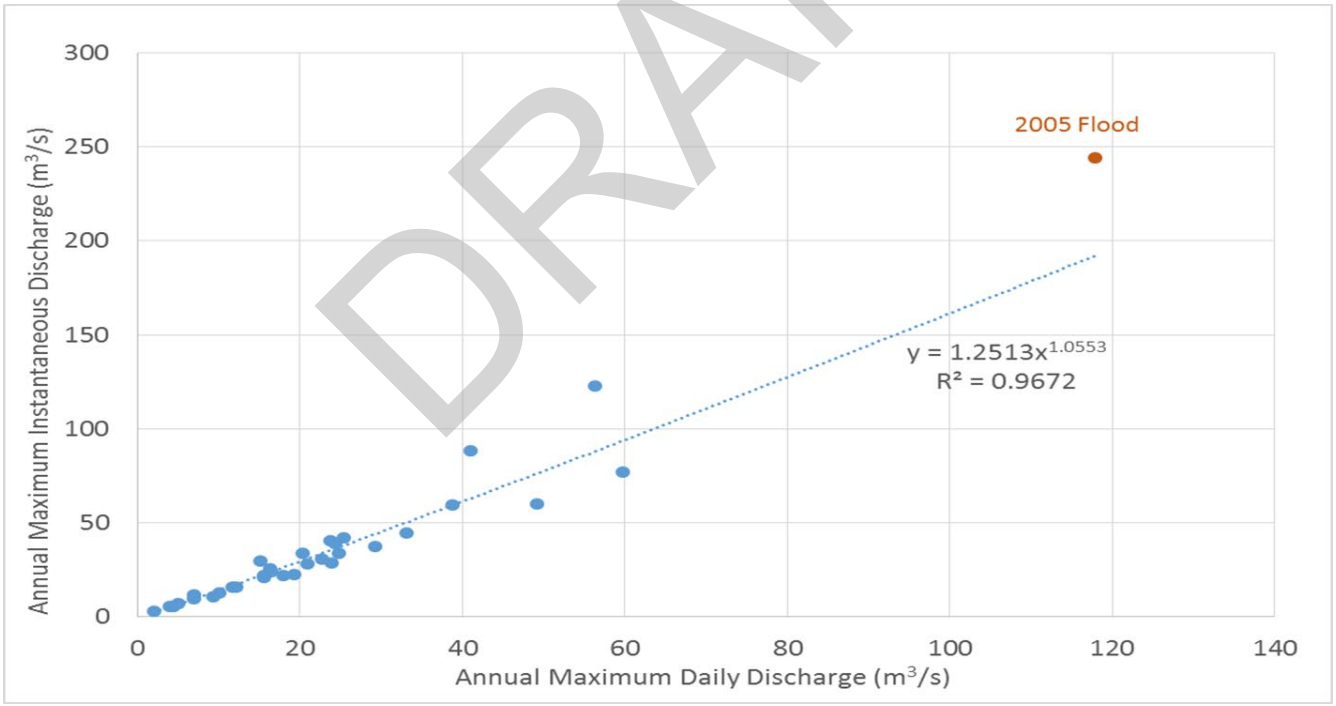
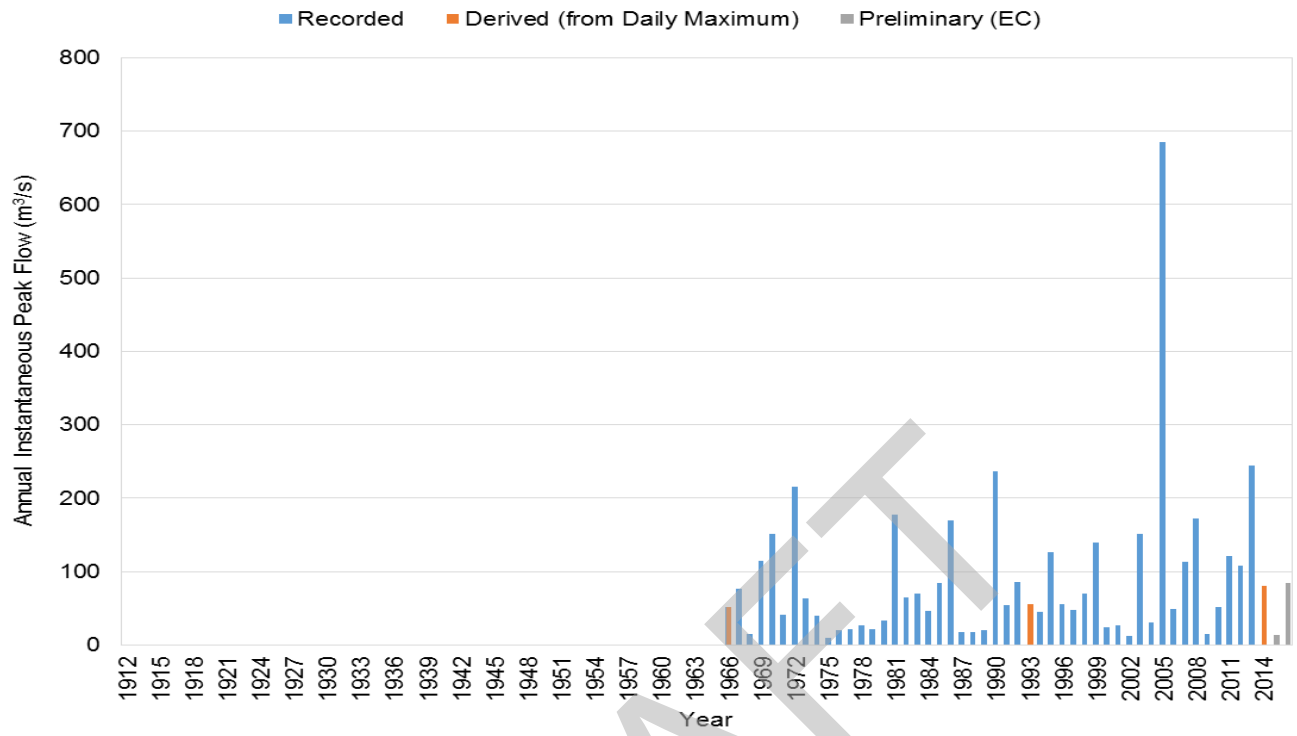


Figure A.14: Node 303 - 05CA002, James River near Sundre



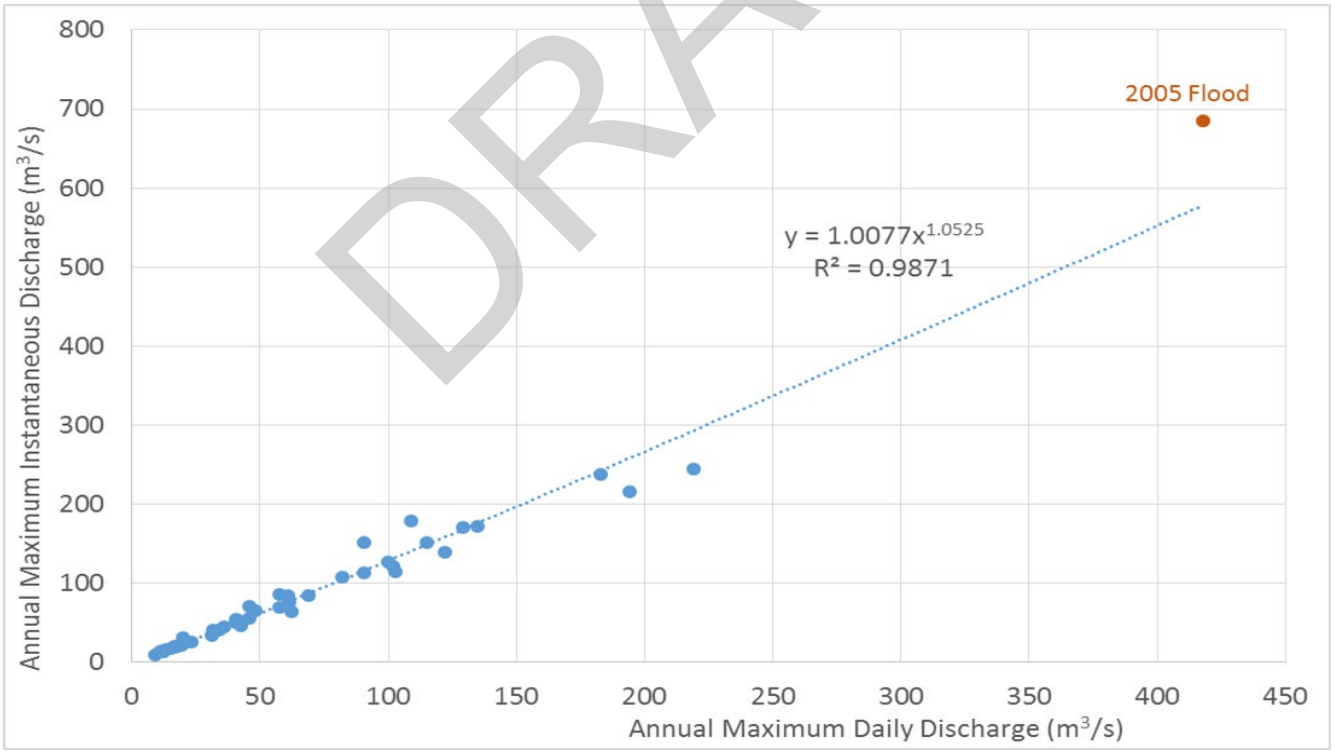
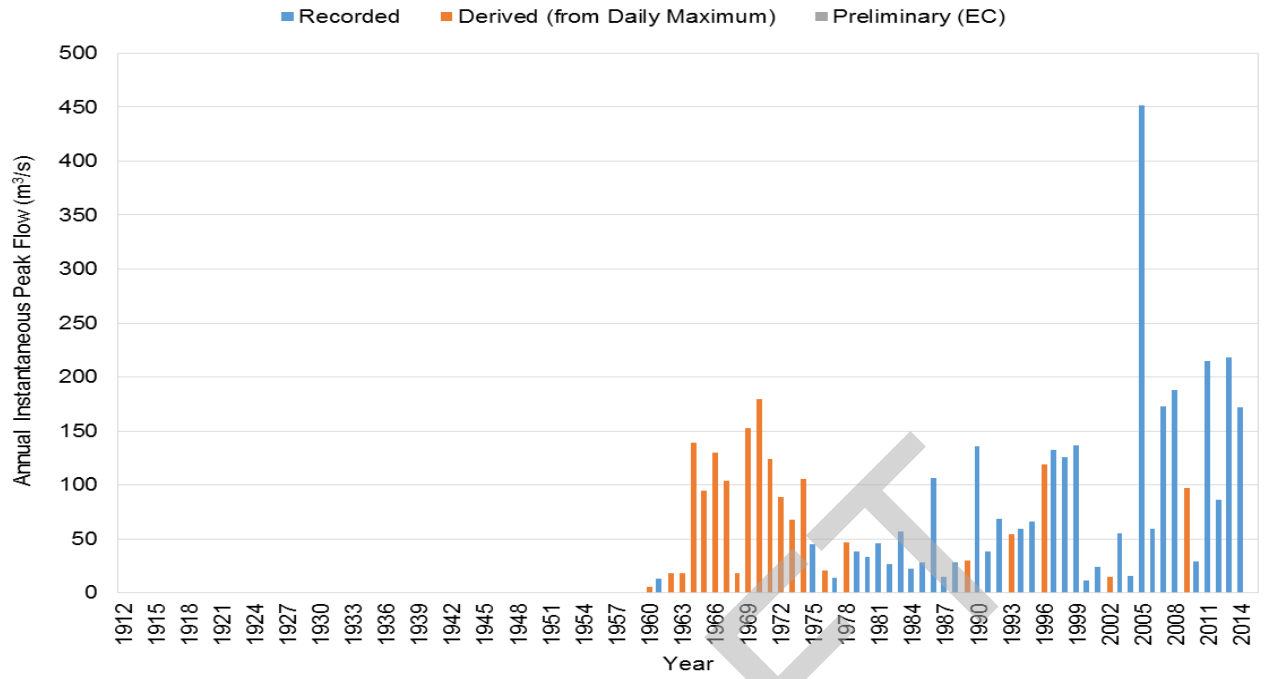


Figure A.15: Node 304 - 05CB001, Little Red Deer River near the Mouth



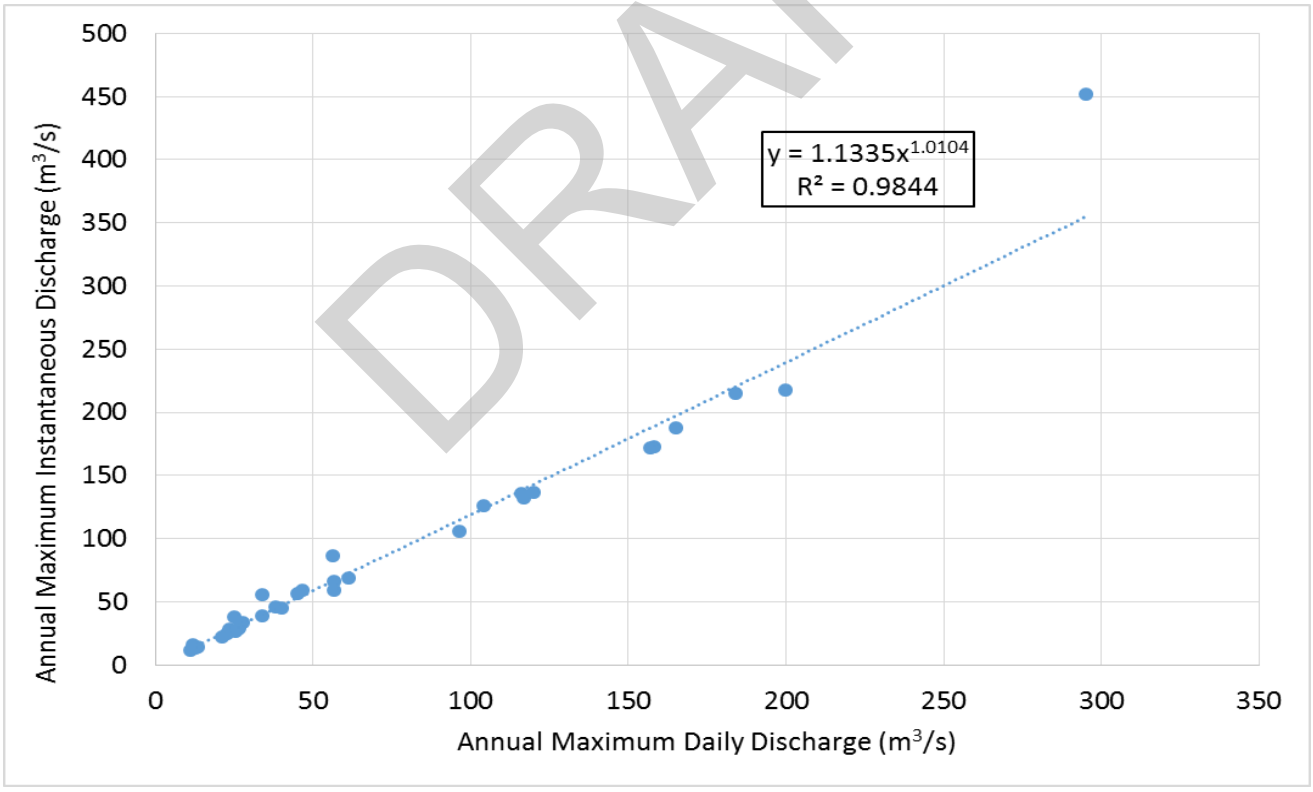
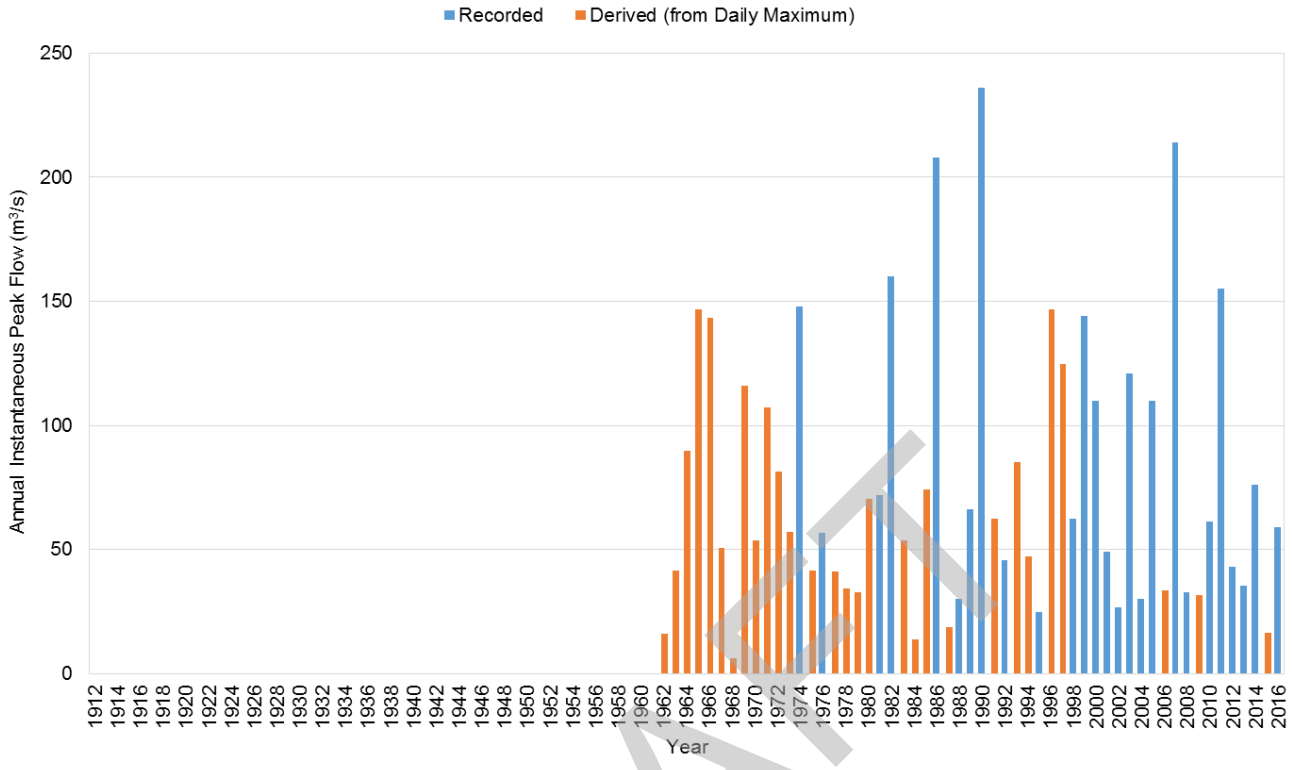


Figure A.16: Node 305 - 05CC007, Medicine River near Eckville



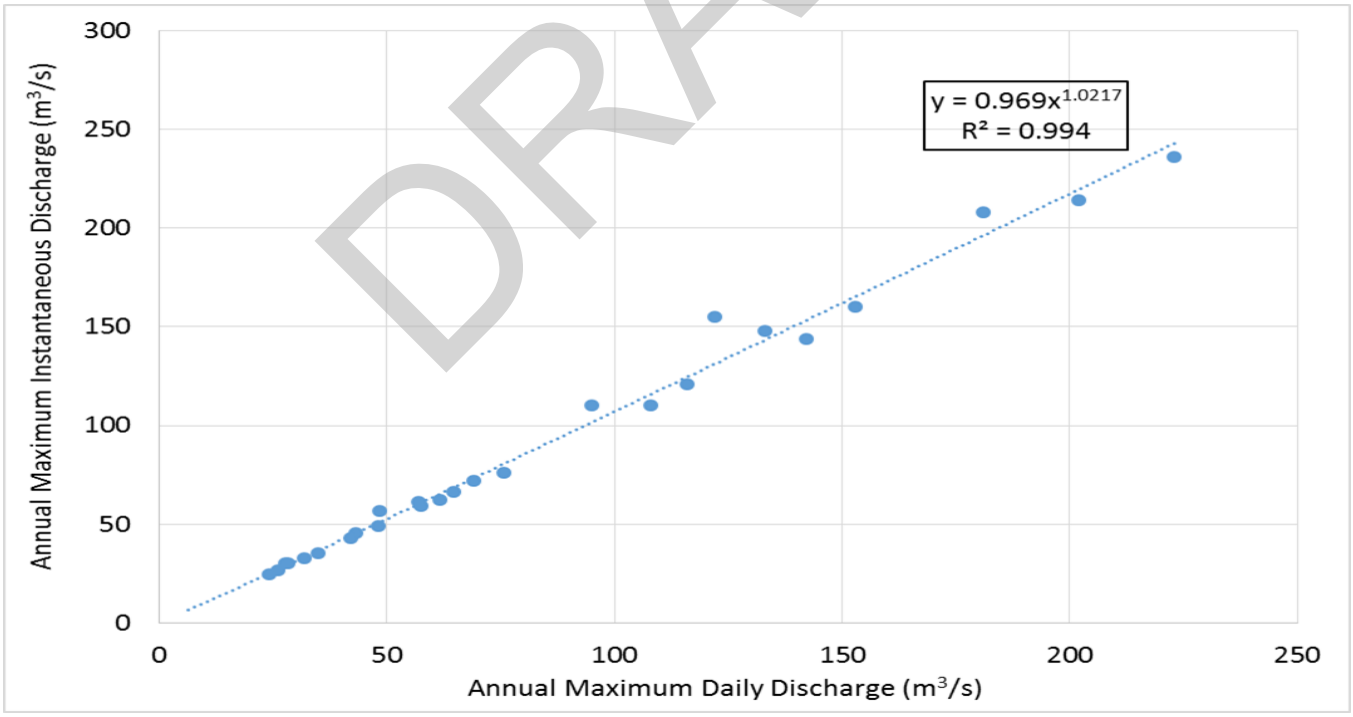
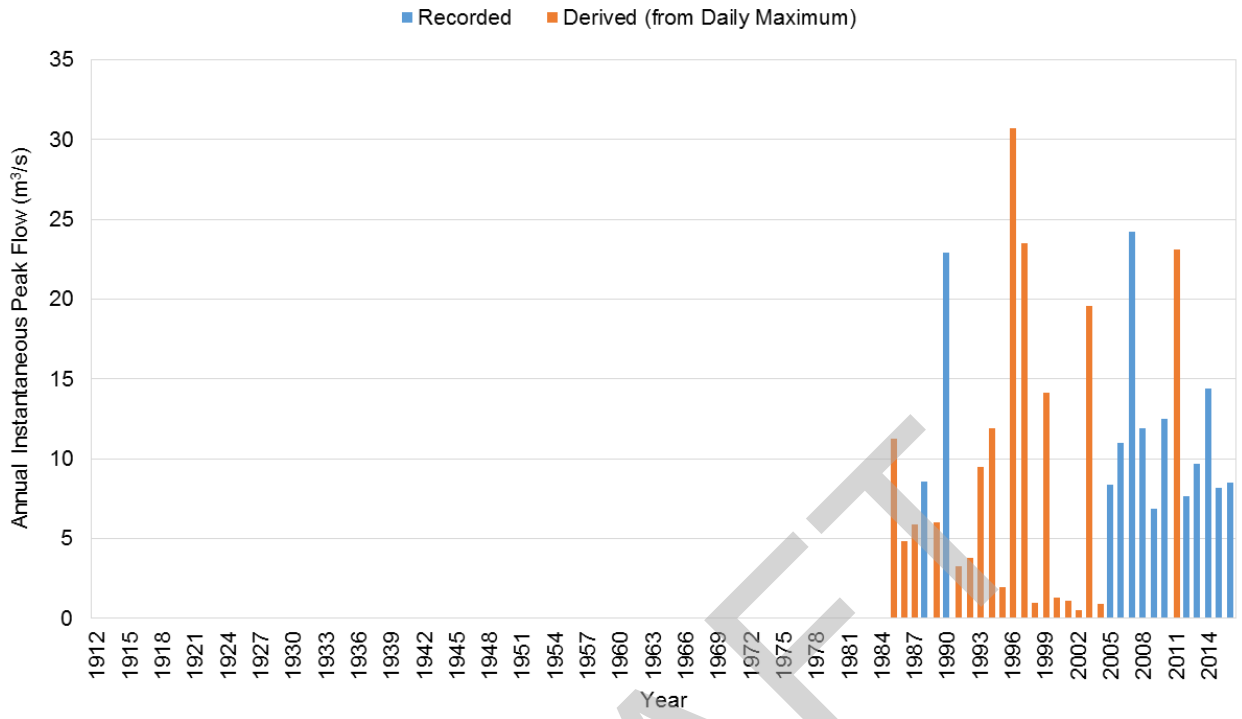


Figure A.17: Node 307 - 05CC011, Waskasoo Creek at Red Deer



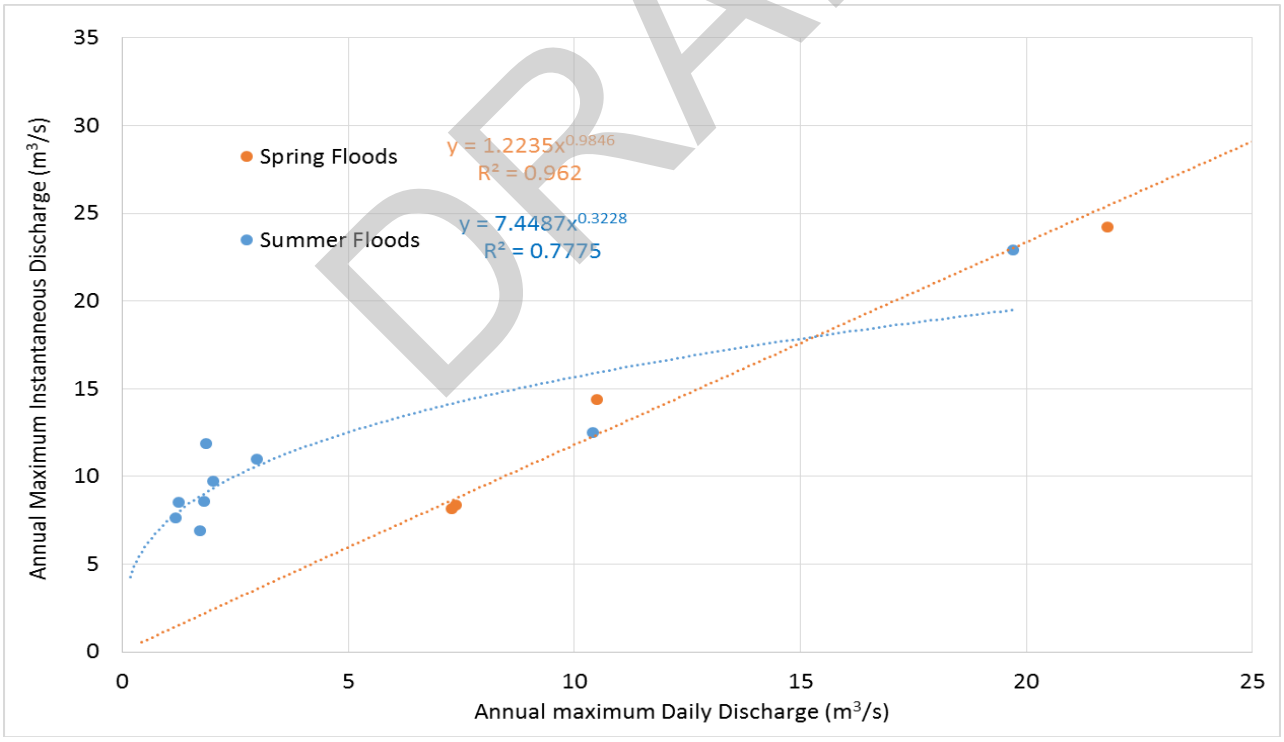
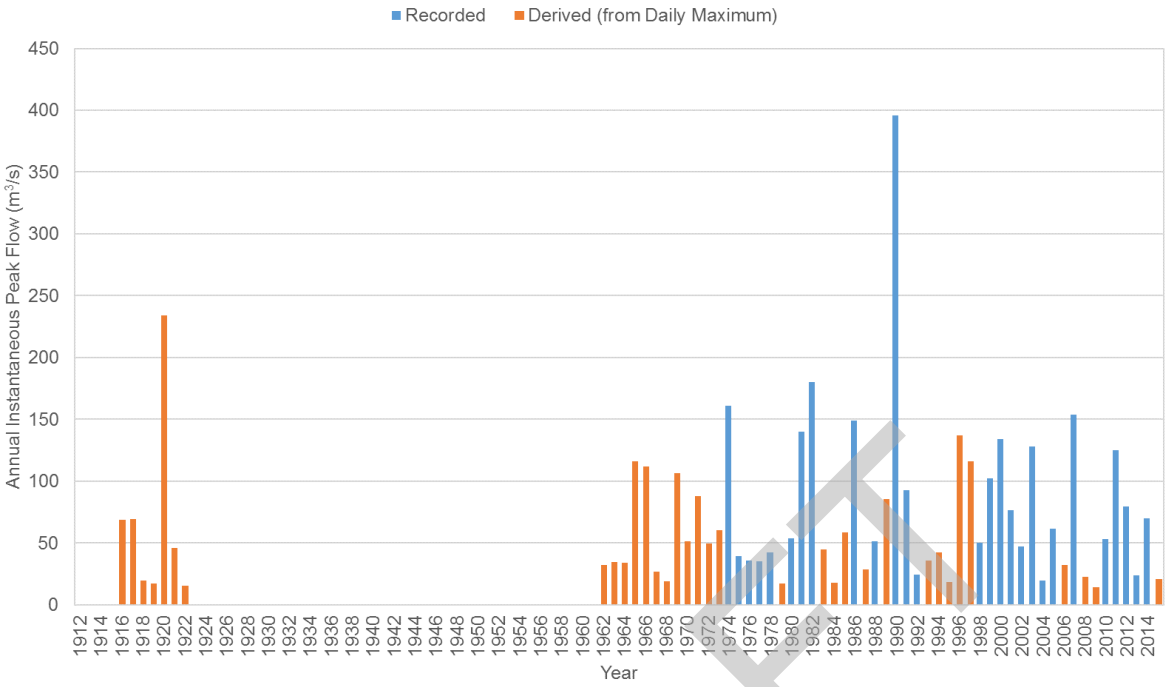


Figure A.18: Node 313 - 05CC001, Blindman River near Blackfalds



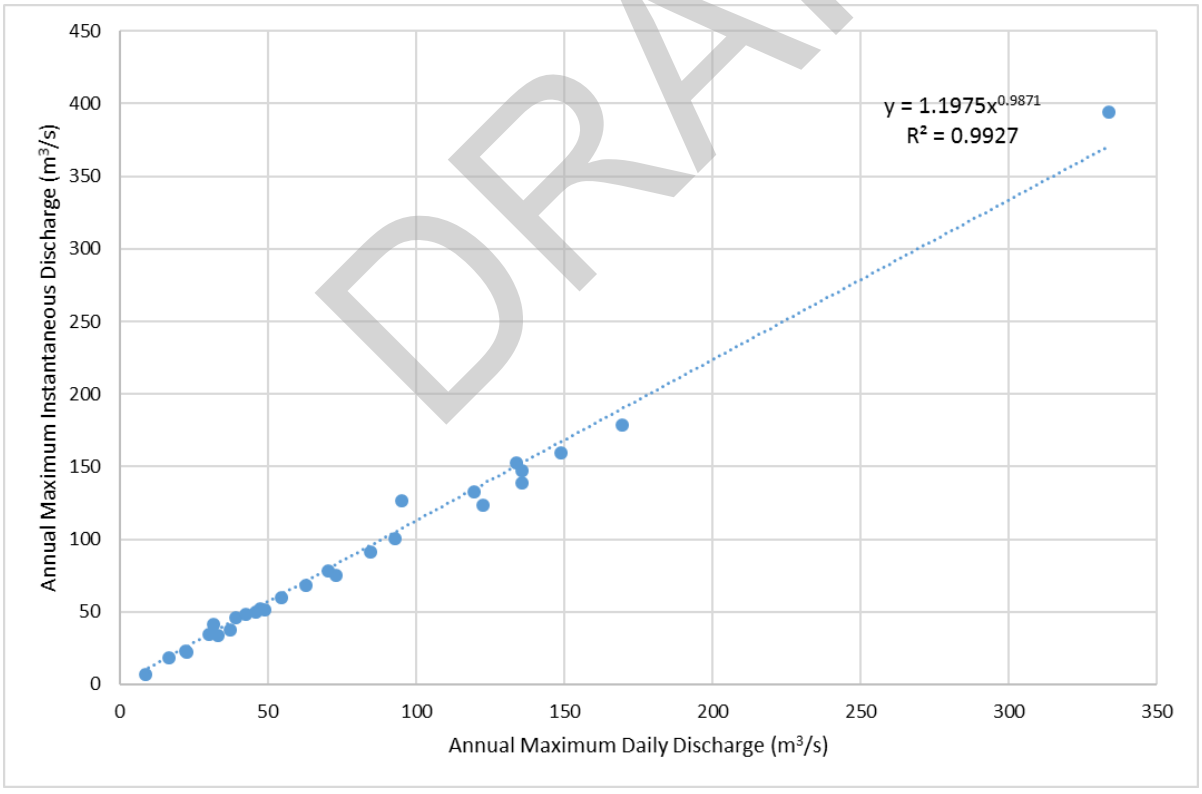
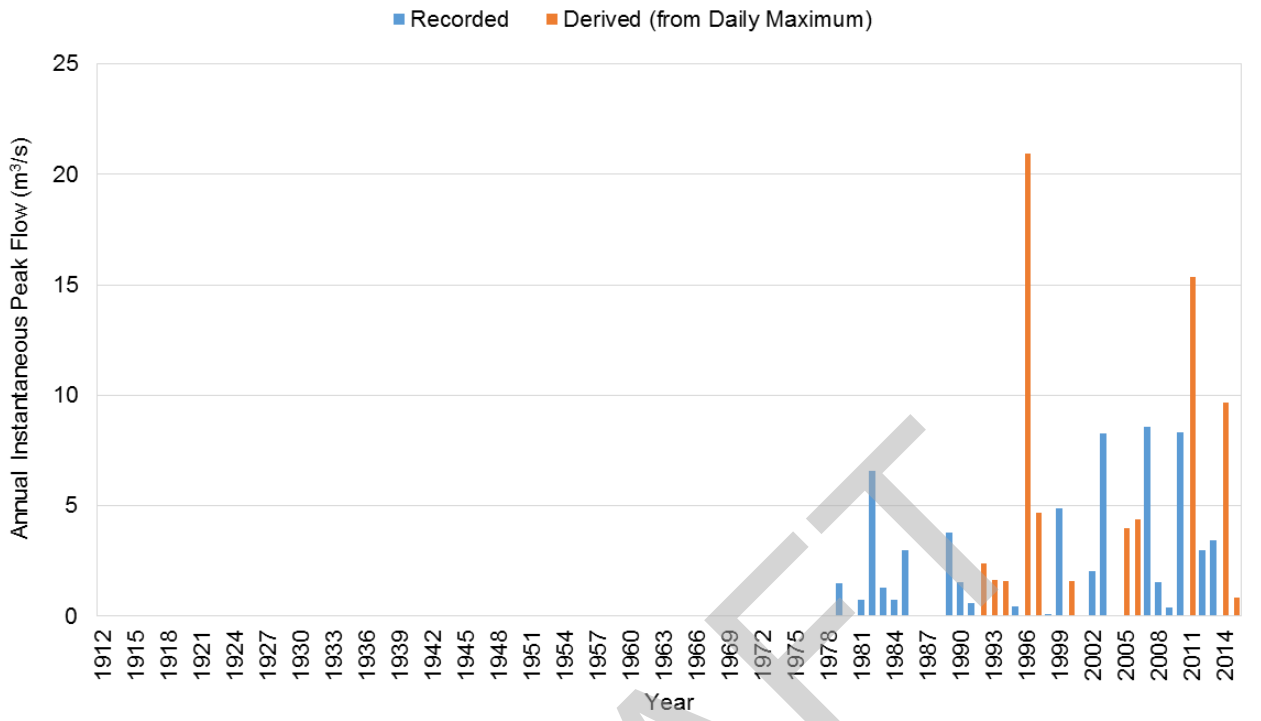


Figure A.19: Node 400 - 05CD006, Haynes Creek near Haynes



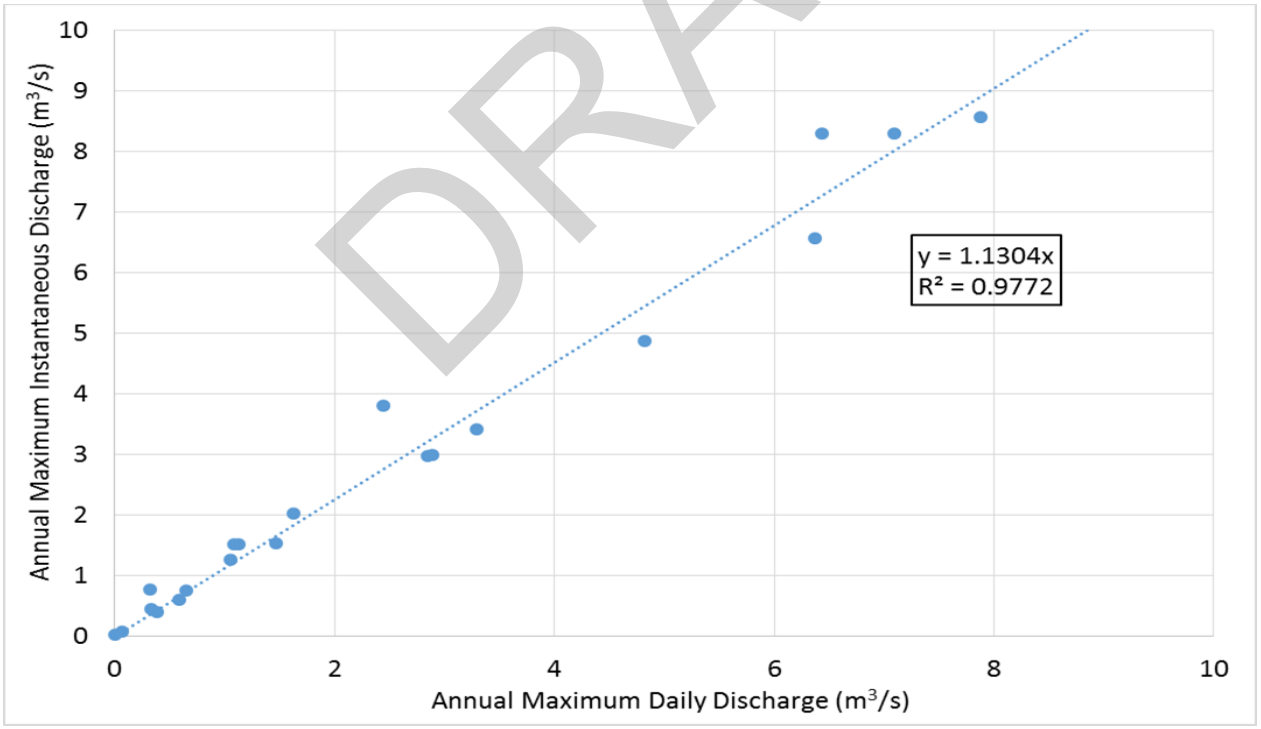


Figure A.20: Node 401 - 05CD007, Parlby Creek at Alix

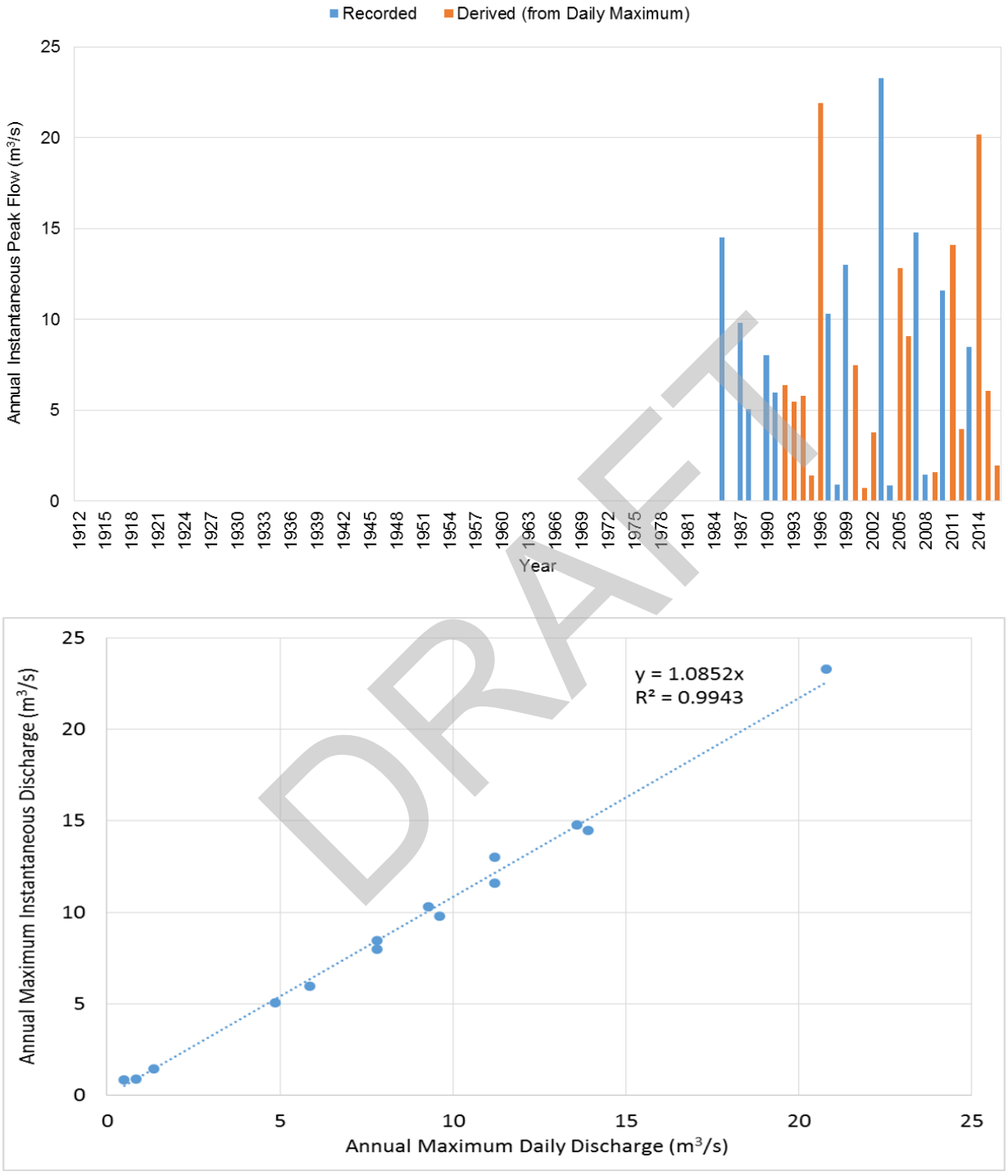
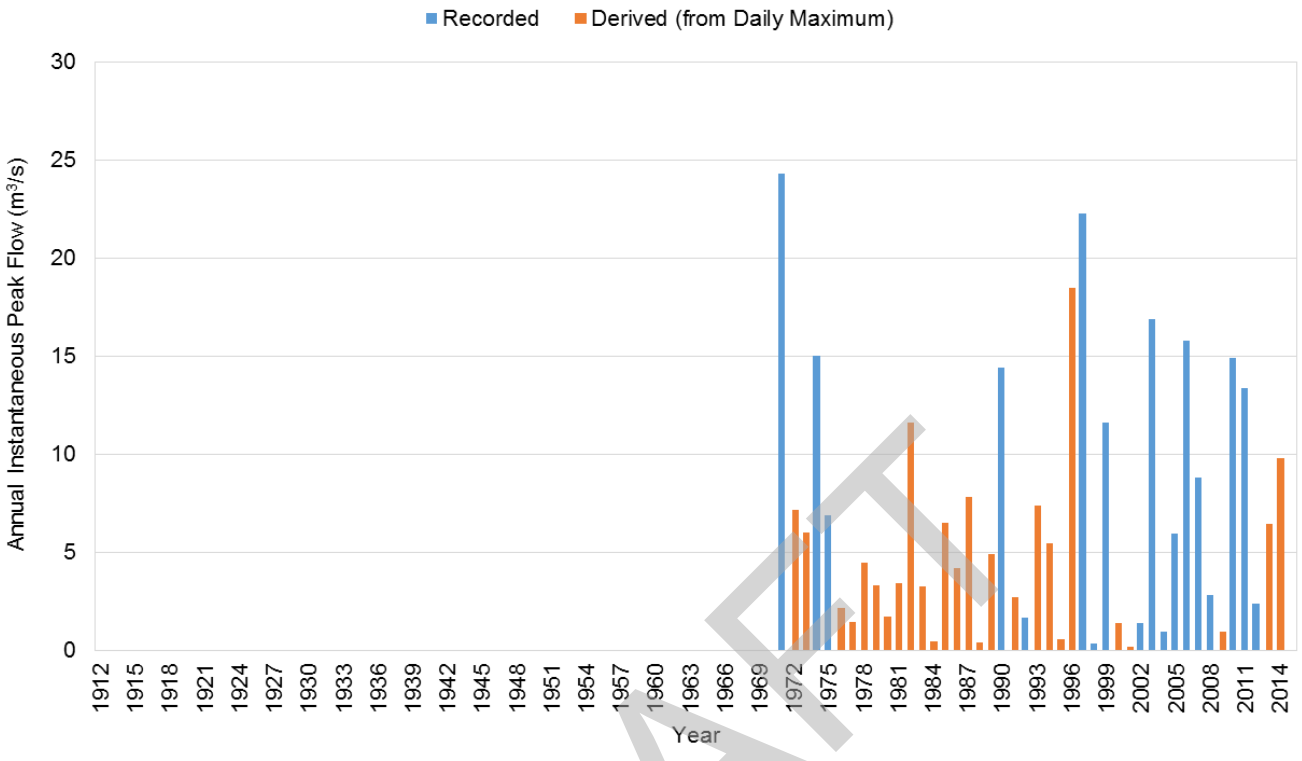
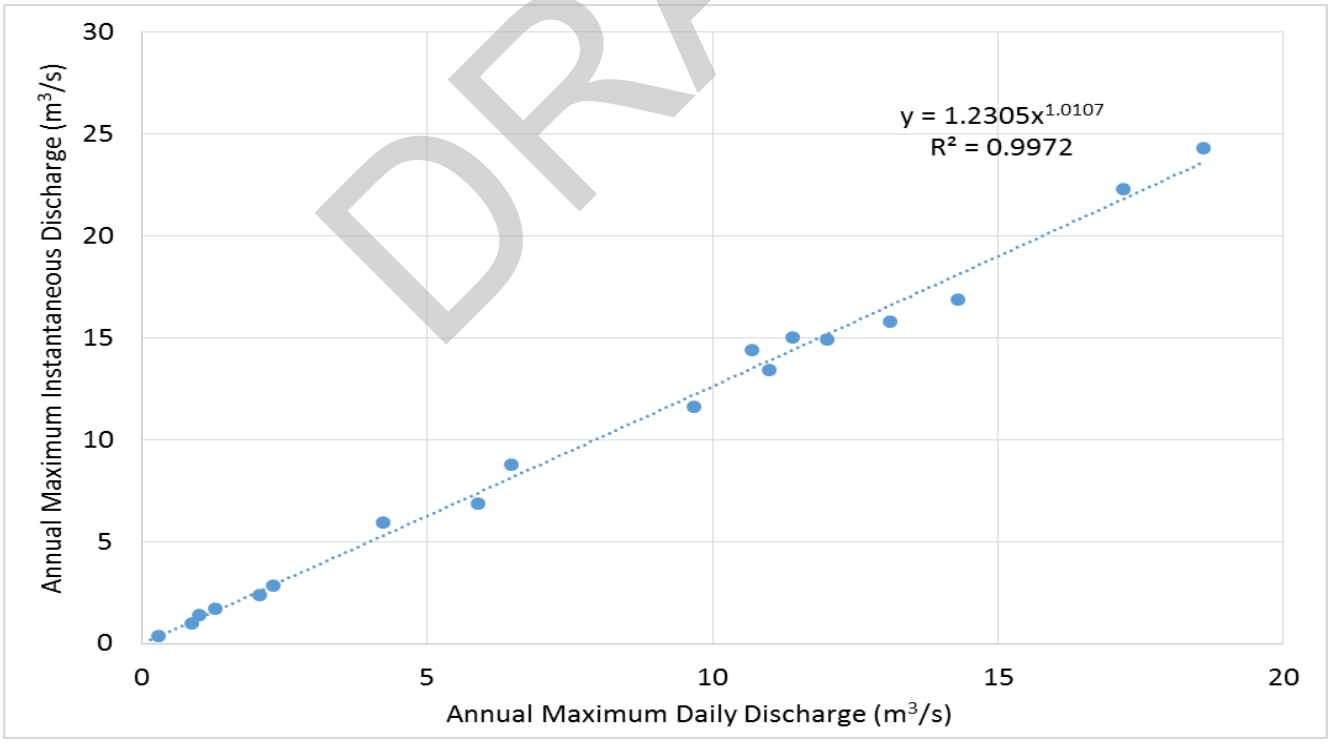


Figure A.21: Node 402 - 05CE018, Threehills Creek below Ray Creek





RED DEER RIVER – Regulated

Figure A.22: Node 108, Red Deer River below Dickson Dam

Annual maximum instantaneous flows were estimated based on the relationship between annual daily maximum flows and annual maximum instantaneous flows at Red Deer River at Red Deer (05CC002) (see Figure A.3).

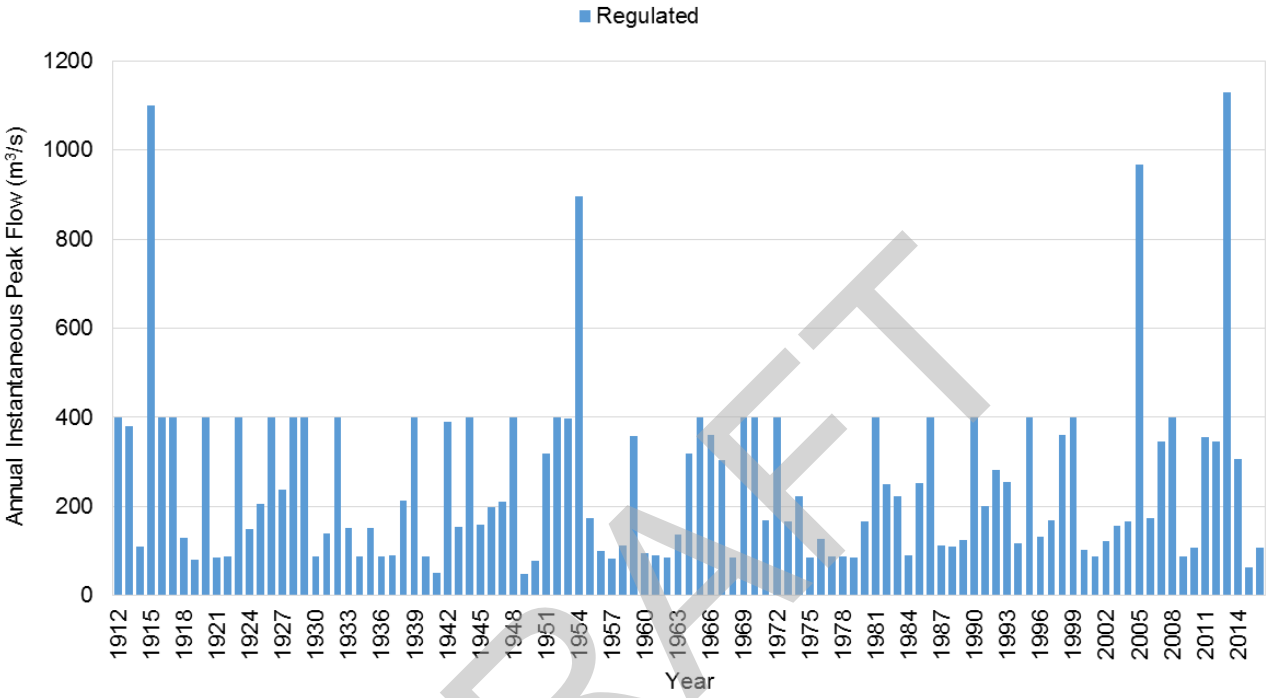
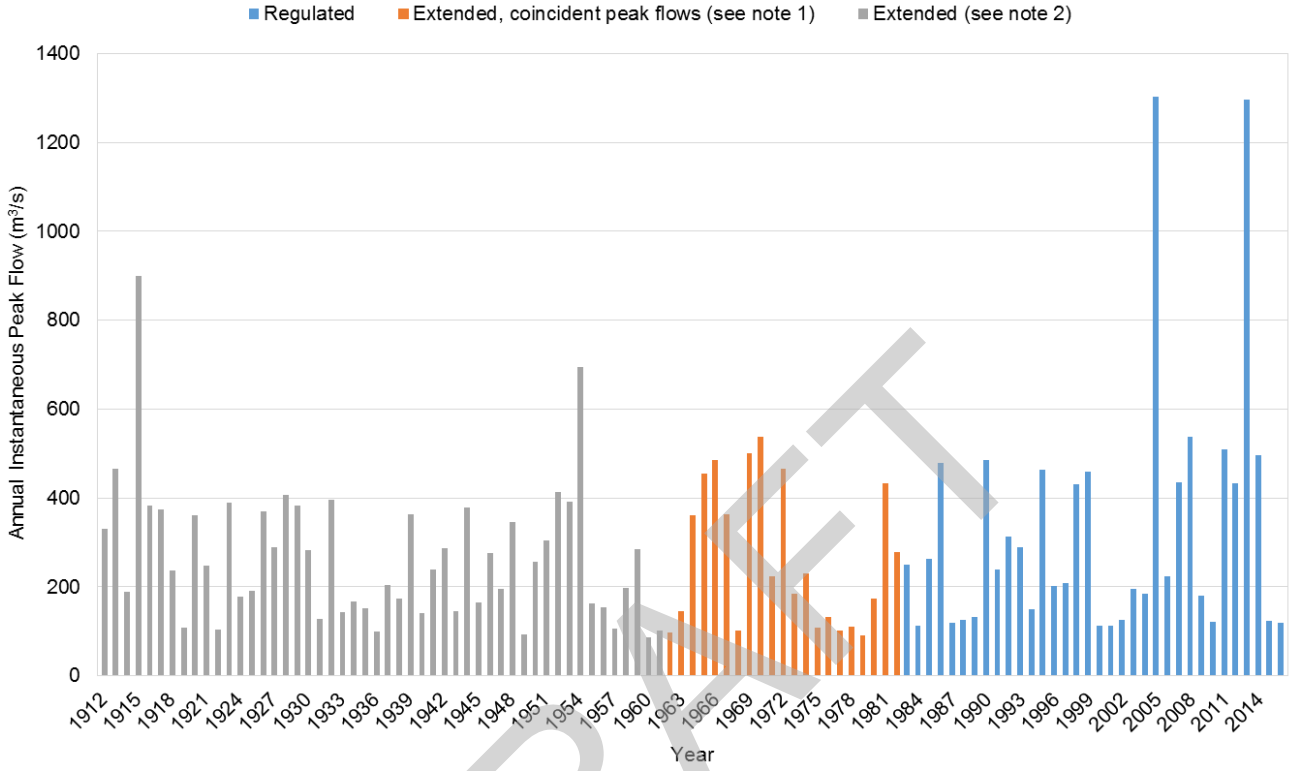


Figure A.23: Node 109, Red Deer River Downstream of Little Red Deer River Confluence

Annual maximum instantaneous flows were estimated based on the relationship between annual daily maximum flows and annual maximum instantaneous flows at Red Deer River at Red Deer (05CC002) (see Figure A.3).

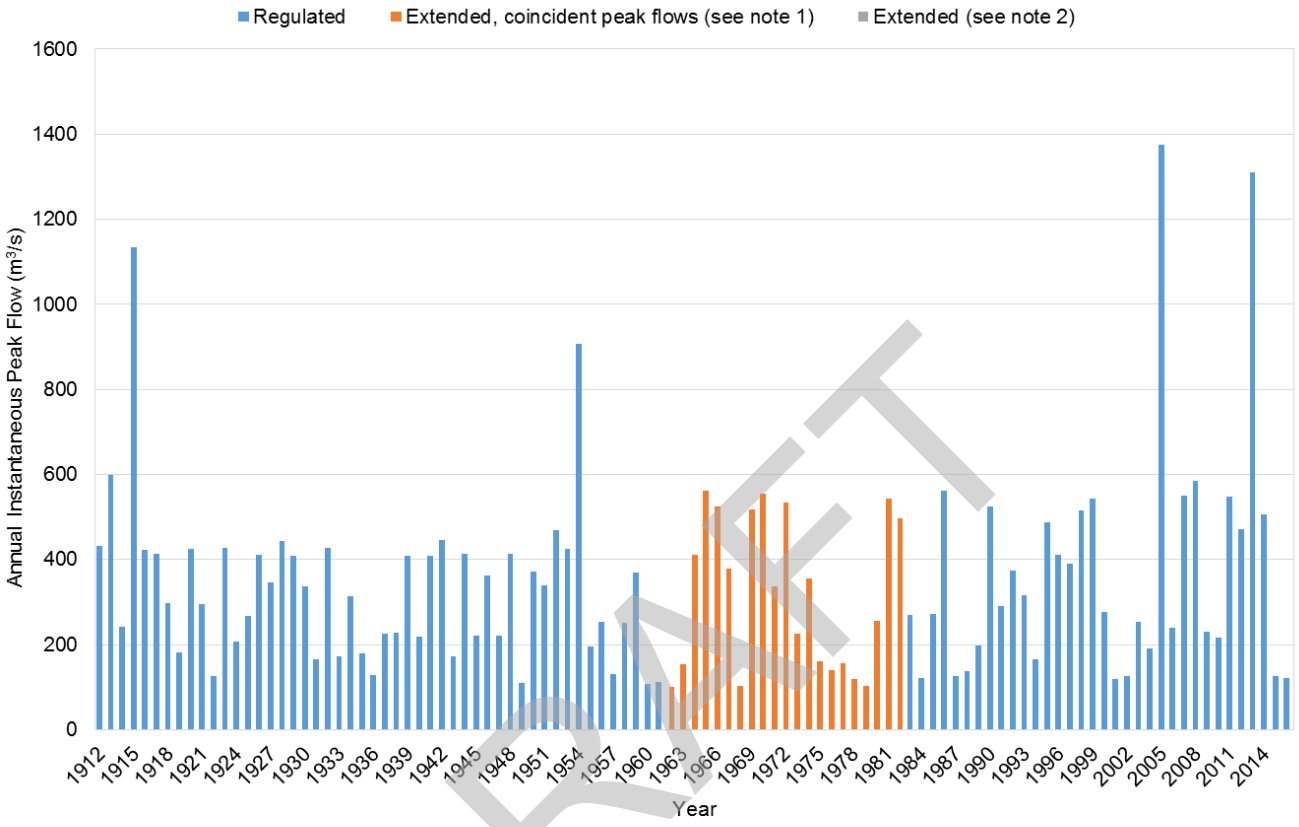


Note 1: Extended by combining Red Deer River above Gleniffer Reservoir (Node 1) and Little Red Deer River near the Mouth (05CB001) assuming coincident peak flows

Note 2: Naturalized flow derived based on relationship established with inflows to Gleniffer Reservoir using naturalized data from 1962 to 2016

Figure A.24: Node 110, Red Deer River Downstream of Medicine River

Annual maximum instantaneous flows were estimated based on the relationship between annual daily maximum flows and annual maximum instantaneous flows at Red Deer River at Red Deer (05CC002) (see Figure A.3).

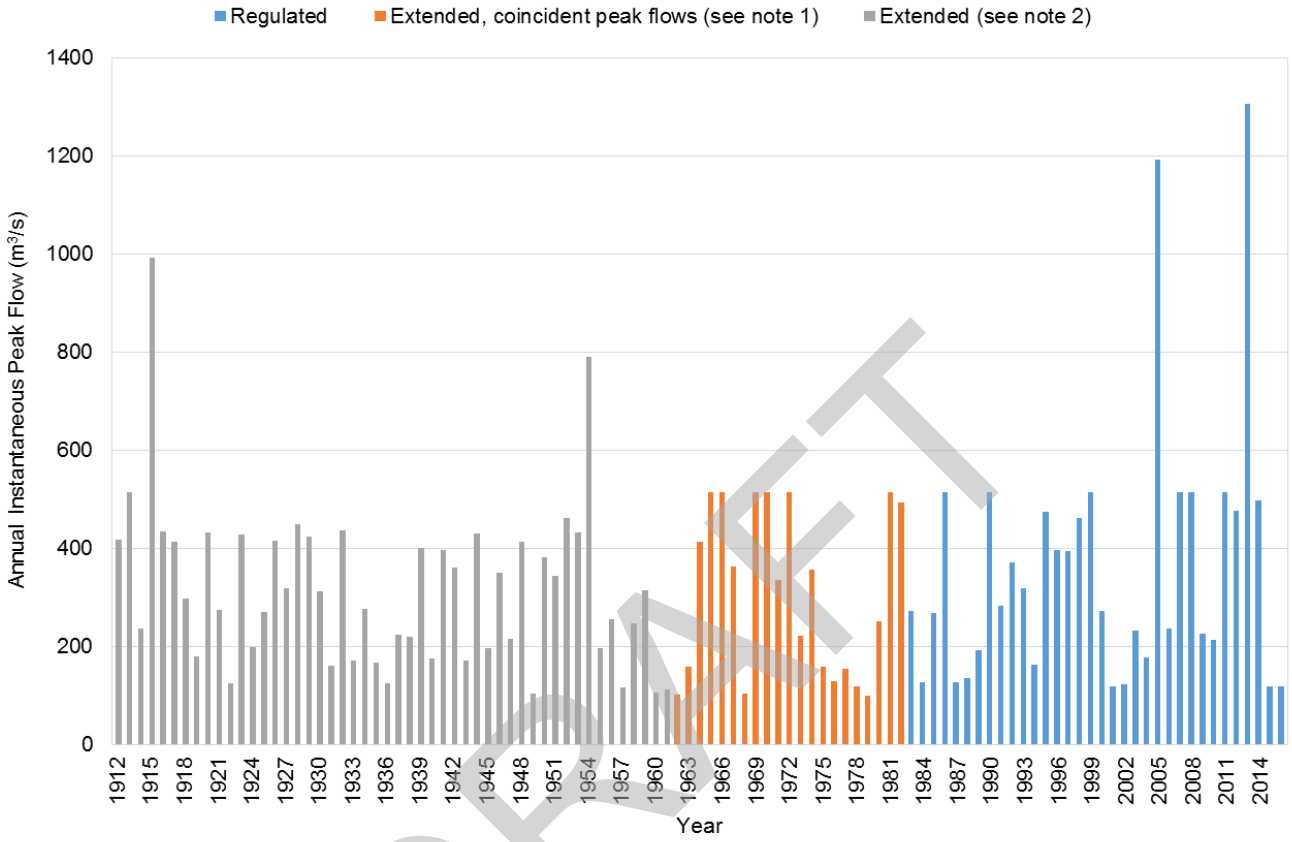


Note 1: Extended by combining Red Deer River Downstream of Little Red Deer River Confluence (Node 2) and Medicine River near Eckville (05CC007) assuming coincident peak flows

Note 2: Naturalized flow derived based on relationship established with flows for Red Deer River at Red Deer using naturalized data from 1962 to 2016

Figure A.25: Node 111, Red Deer River at the City Red Deer

Annual maximum instantaneous flows were estimated based on the relationship between annual daily maximum flows and annual maximum instantaneous flows at Red Deer River at Red Deer (05CC002) (see Figure A.3).



Note 1: Extended by combining Red Deer River Downstream of Little Red Deer River Confluence (Node 2) and Medicine River near Eckville (05CC007) assuming coincident peak flows and routed to the Node

Note 2: Regulated flow derived based on relationship established with flows for Red Deer River at Red Deer using regulated data from 1962 to 2016

Figure A.26: 05CC002 / Node 202, Red Deer River at Red Deer

Annual maximum instantaneous flows were estimated based on the relationship between annual daily maximum flows and annual maximum instantaneous flows at Red Deer River at Red Deer (05CC002) (see Figure A.3).

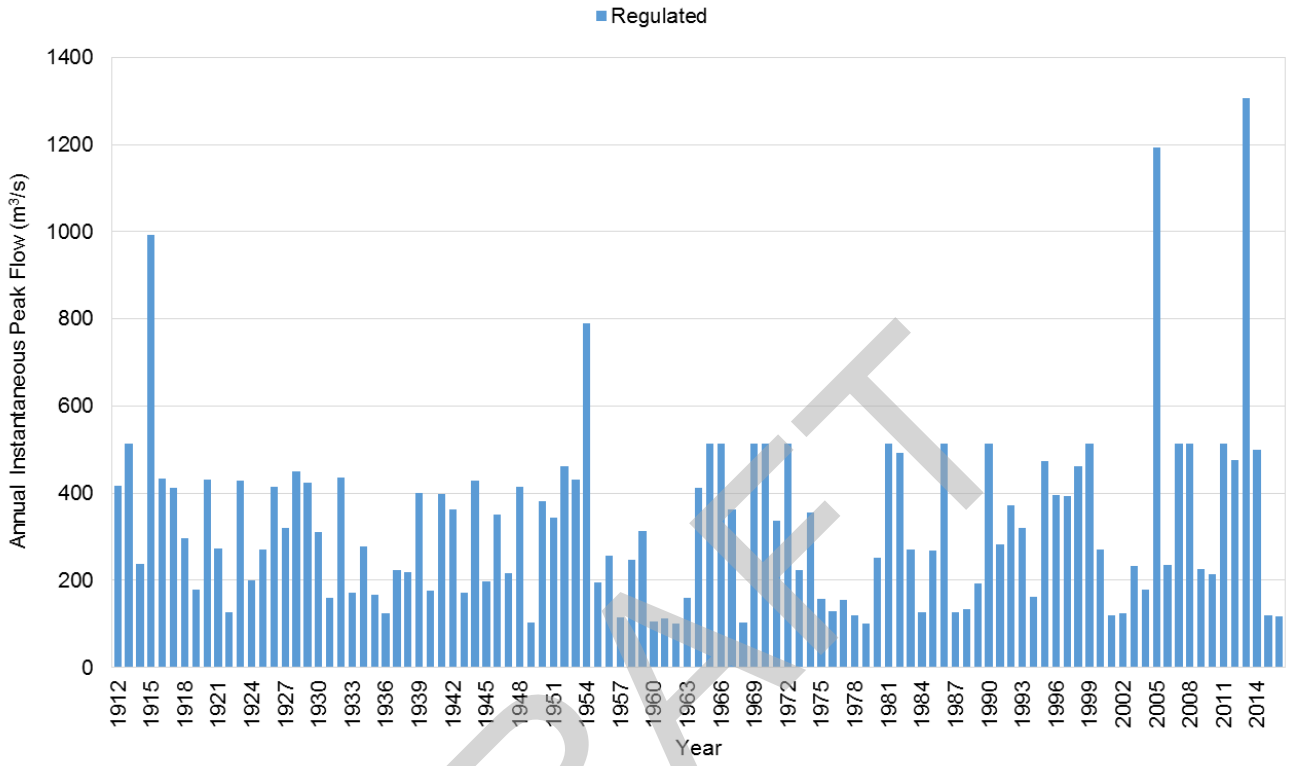
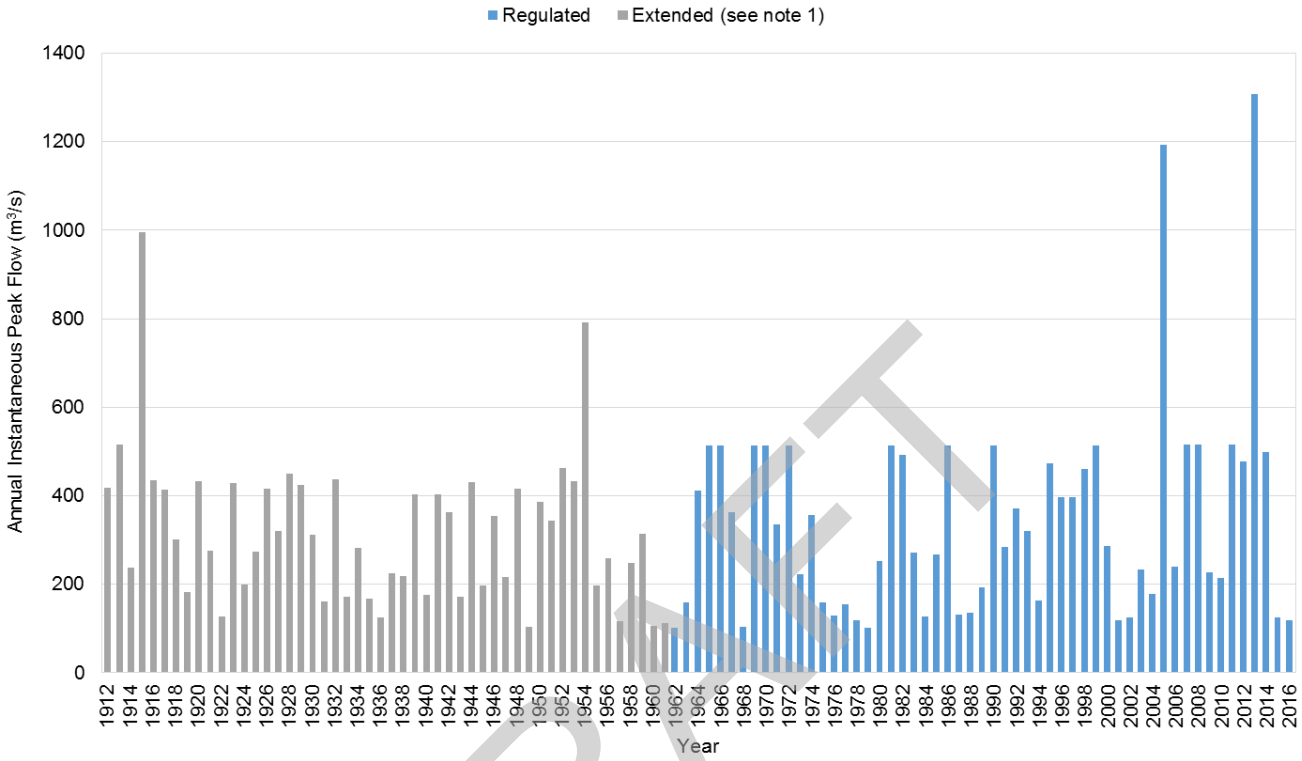


Figure A.27: Node 112, Red Deer River below Waskasoo Creek Confluence

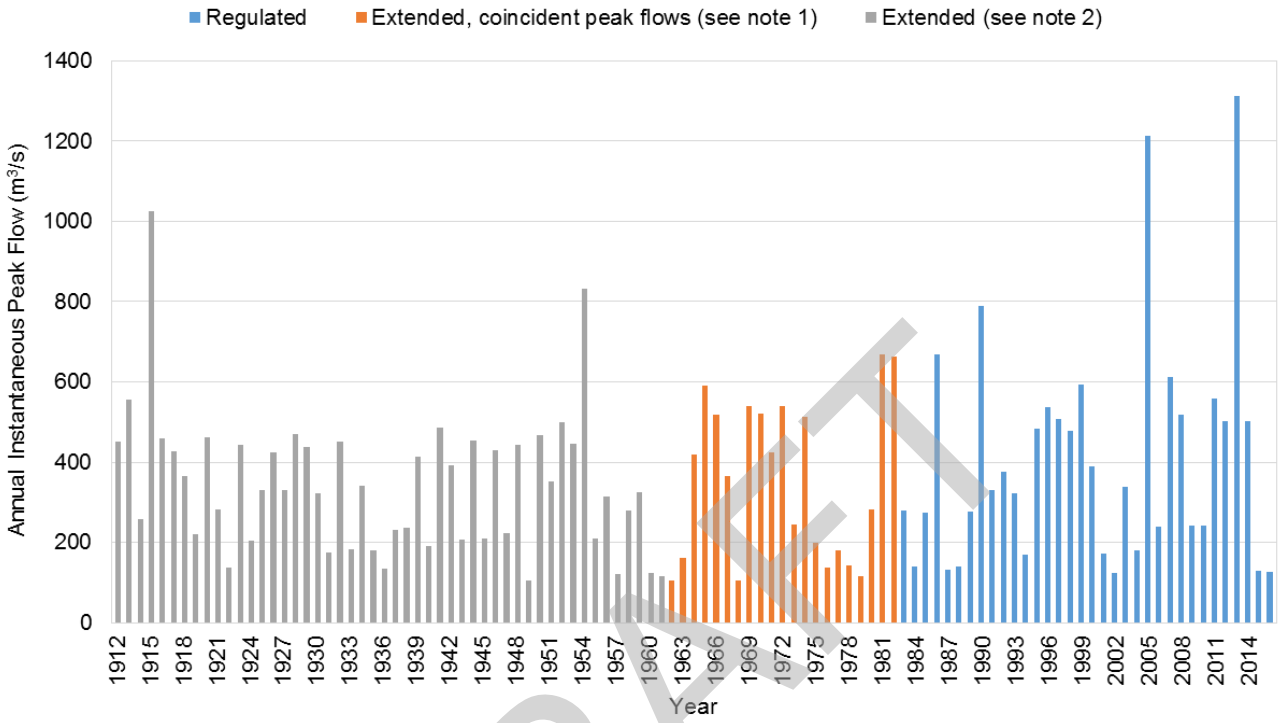
Annual maximum instantaneous flows were estimated based on the relationship between annual daily maximum flows and annual maximum instantaneous flows at Red Deer River at Red Deer (05CC002) (see Figure A.3).



Note 1: Regulated flow derived based on relationship established with flows for Red Deer River at Red Deer using regulated data from 1962 to 2016

Figure A.28: Node 114, Red Deer River below Blindman River Confluence

Annual maximum instantaneous flows were estimated based on the relationship between annual daily maximum flows and annual maximum instantaneous flows at Red Deer River at Red Deer (05CC002) (see Figure A.3).

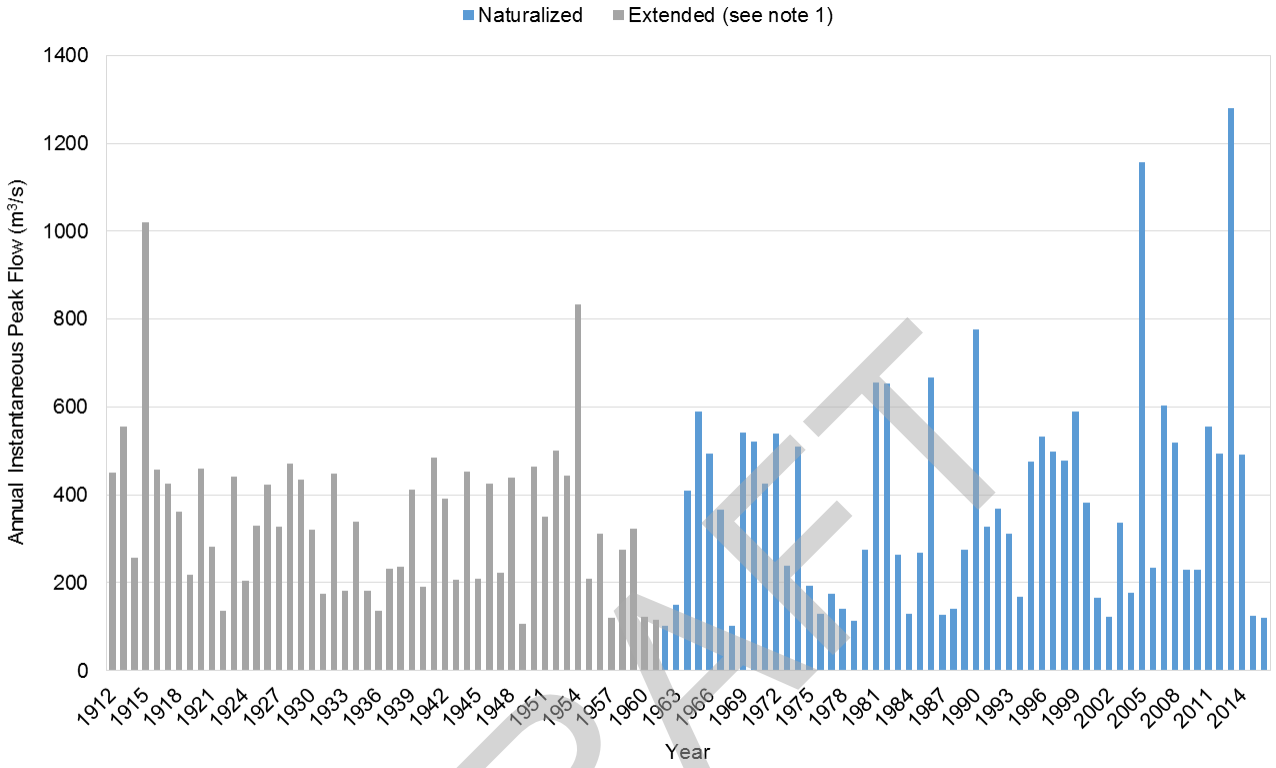


Note 1: Extended by combining Red Deer River at Red Deer (Node 4) and Blindman River near Blackfalds (05CC001) assuming coincident peak flows

Note 2: Regulated flow derived based on relationship established with flows for Red Deer River at Red Deer using regulated data from 1962 to 2016

Figure A.29: Node 115, Red Deer River at Highway 11

Annual maximum instantaneous flows were estimated based on the relationship between annual daily maximum flows and annual maximum instantaneous flows at Red Deer River at Red Deer (05CC002) (see Figure A.3).



Note 1: Regulated flow derived based on relationship established with flows for Red Deer River at Red Deer using regulated data from 1962 to 2016

APPENDIX B

Naturalized and Regulated Daily Flows and Flood Flow Routing at Key Locations

B1.0 INTRODUCTION

The work completed in this study involves generation of daily natural flows for all relevant location of interest in the Red Deer River basin. The locations include Dickson Dam, downstream of major tributaries and Water Survey of Canada (WSC) flow gauging locations. The principal approach for flow naturalization involved removal of the effects of storage and diversions. Flow naturalization was conducted reach by reach from upstream location (i.e., Red Deer River at Dickson Dam) to the downstream location (Red Deer River at Highway 11). The approach, known as the Project Depletion Method and was used by AEP in the past, and was built into the River Basin Assessment Tool (RBAT) model. Apart from minor modifications, the following section follows the explanation of the Project Depletion Method that has been laid out in the RBAT User's Manual.

B2.0 AVAILABILITY OF INPUT DATA

The process of developing natural flow estimates requires the use of historic records of reservoir levels and outflows from the date Dickson Dam started its operation. This appendix describes the methodology for calculating natural flows as well as how this methodology was implemented at each location of interest given the available data. It should be noted that the primary purpose of developing natural flows was to properly assess incoming annual peak flows for as many years as possible. Naturalized annual peak flows constitute a principal input into the hydrologic frequency analyses. Annual peak flows were assessed for as many years as possible, as further explained in subsequent sections that provide more information about each storage site where natural flow series were developed.

B3.0 PROJECT DEPLETION METHOD

Alberta Environment uses the Project Depletion Method to calculate natural flows on all major rivers in Alberta. The same methodology is employed by the Prairie Provinces Water Board (PPWB). The PPWB consists of representatives from Environment Canada (representing the Federal Government) and the representatives of the three Prairie Provinces. The short summary that explains the project depletion method in this section follows closely the documentation of the Natural Flow Computation Program (NFCP) program used in this study. Technical specifications for NFCP were approved by the PPWB in November of 2008.

Natural flows are river flows that would have been observed at selected locations in a river basin assuming there had been no human intervention by operation of large storage reservoirs or withdrawals. The most common approach to estimate natural flows is the Project Depletion Method, which is essentially aimed at “undoing” the impacts of human intervention in a systematic way, reach by reach, in a downstream progression.

The calculation procedure is explained below for a small example shown in Figure B1 that contains all elements found in complex river basins. There are two river reaches with a reservoir R1 at their confluence. In this example naturalized flow is calculated at the reservoir site. There is one diversion into the reservoir (D1) and one return flow (RT1) into the reservoir, one diversion channel out of the reservoir (D2), and regulated outflow from the reservoir into natural channel reach C3. The general approach to calculate naturalized flows at any location is to estimate local runoff which originates between the given location and the closest upstream locations at which natural flows had already been evaluated. Denote the naturalized flow at reservoir as QR1 and the local runoff between natural flows Q1, Q2 and the reservoir as LR. The naturalized flow at the reservoir site can then be calculated as:

$$Q_{R1} = Q_1 + Q_2 + LR \quad (1)$$

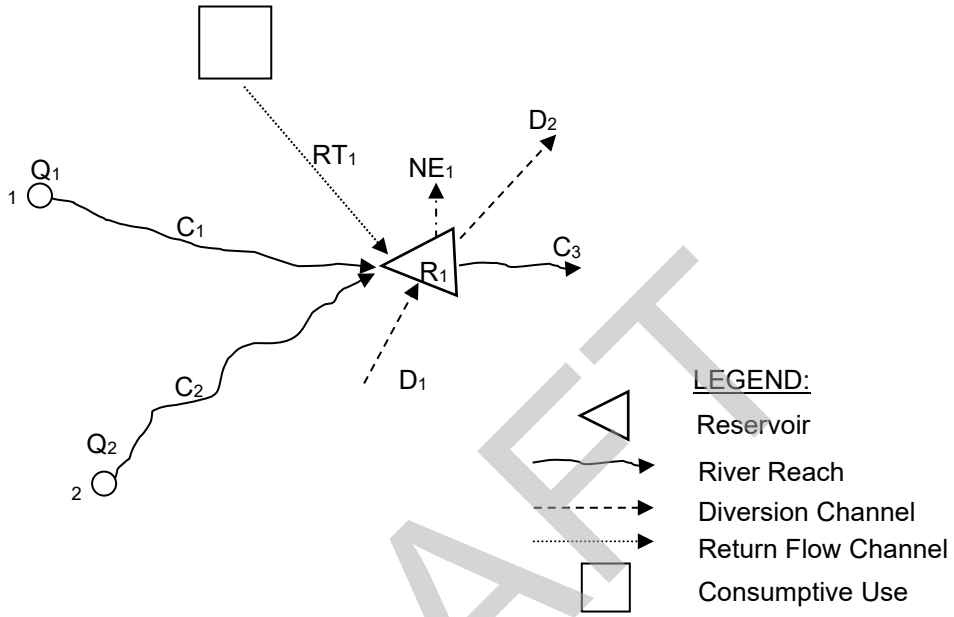


Figure B1: Sample Schematic for Calculation of Naturalized Flows

Consequently, the principal component of deriving naturalized flows is determination of the local runoff LR. Assuming Qr1 and Qr2 are the recorded flows at locations 1 and 2, LR for the reservoir in Figure B1 can be calculated using the following equation assuming average flow over time step t:

$$LR = Q_{C3} + Q_{D2} - Q_{RT1} - Q_{D1} + \Delta V/t - Q_{r1} - Q_{r2} \quad (2)$$

Where:

Q_{C3} The recorded flow in channel C_3

Q_{D1} Flow in diversion channel D_1

Q_{D2} Flow in diversion channel D_2

Q_{RT1} Flow in return flow channel RT_1

$\Delta V/t$ Reservoir storage change over time step t

Reservoir storage change is further evaluated using the starting and ending storage (Vs and Ve) for a time step, along with adjustments for net evaporation (evaporation minus precipitation) for a given time interval t. Note that the sign for net evaporation is reversed since the consideration is to remove the effect of net evaporation (i.e. put the evaporation loss back in the river since this loss would not have happened if the reservoir had not been built):

$$\frac{\Delta V}{t} = \frac{Ve - Vs}{t} + \frac{(E - P)[A(Ve) + A(Vs)]}{2t} \quad (3)$$

Where:

V_e Volume at the end of time step *t* (m^3)

V_s Volume at the start of time step *t* (m^3)

P Total precipitation over time step *t* (m)

E Total evaporation from the reservoir surface over time step *t* (m)

$A(V_e)$ Surface area (m^2) corresponding to the ending volume *Ve*

$A(V_s)$ Surface area (m^2) corresponding to the starting volume *Vs*

To summarize, local runoff LR can in general be assessed by conducting a water balance calculation for a sub-catchment which is delineated by the downstream point for which LR is evaluated and the upstream control points where recorded flow series are available. The general expression is:

$$LR = \sum_{i=1}^{m} Q_i - \sum_{j=1}^{n} Q_j + \sum_{k=1}^{l} \frac{\Delta V_k}{t} \quad (4)$$

Where:

Q_i Average outflows (i=1, m) from a sub catchment within time step *t*

Q_j Average inflows (i=1, m) into a sub catchment within time step *t*

While the storage change term $\Delta V/t$ is summed up over all storage reservoirs in the sub-catchment area under consideration. Inflows and outflows into a sub-catchment include all diversions and return flows into it, as well as diversions out of it. Normally, naturalized flows should be calculated at all on-stream reservoir locations, especially when reservoirs have sizeable live storage.

Equation (1) suggests that naturalized flows be first determined at upstream locations (e.g. locations 1 and 2 in the example in Figure B1). The calculation then proceeds in the above manner for all requested locations in the river basin in a downstream progression. It should be noted that for short (e.g. daily) time steps, the length of river reaches along channels C1 and C2 may require the use of channel routing, such that the routed outflow from these channels takes part in the mass balance calculation at the reservoir node, both for calculating local runoff LR, which would require the routing of recorded flows along these channels, and for calculating the naturalized flow, which would require routing of the naturalized flow estimates previously made at nodes 1 and 2. AEP uses the Wilson's routing equation in the Hydrol model which was borrowed from the Streamflow Synthesis and Reservoir Regulation (SSARR) model. A brief description of Wilson's equation is provided below.

As with the other river routing methods, the governing equation is related to channel storage change over a time step, which is a function of average inflow and outflow:

$$\frac{I_{t-1}+I_t}{2}-\frac{O_{t-1}+O_t}{2}=\frac{\Delta S}{t} \quad (5)$$

By subtracting both sides of the above equation with O_{t-1}, multiplying by $t/(O_t-O_{t-1})$ and by letting $\Delta S/(O_t-O_{t-1}) = TS$, the above equation becomes:

$$Ot=\frac{\left[\frac{I_{t-1}+I_t}{2}-O_{t-1}\right]\cdot t}{TS+\frac{t}{2}}+O_{t-1} \quad (6)$$

Where the term *TS* represents the average travel time along a river reach for given flow conditions, evaluated either by reading from the *TS vs Q* table or by using a functional form of the travel time vs flow curve as:

$$TS=\frac{Kts}{\left(\frac{O_{t-1}+O_t}{2}\right)^n} \quad (7)$$

The routing coefficients *Kts* and n must previously be determined by finding the best fit curve for a given set of the available *(Ts,Q)* coordinates. Usually, *Ts* can be determined for any given flow rate by linear interpolation from a table of *(Ts,Q)* points (these tables were provided by Alberta Environment and used in this project). In the above definition of *Ts*, the base of the denominator shown below represents the average channel flow over a time step as the arithmetic average of the outflows at the beginning and the end of the time step:

$$\frac{O_{t-1}+O_t}{2}$$

Various implementations of the SSARR method may rely on different estimates of the average channel flow during a given time step (which may also include inflows into the channel in some form). The method relies on the established empirical relationship between the travel time and flow for a given channel. Once this relationship is available, the calibration consists of deciding how many sequential phases a given river reach should be divided into, which is conducted using repeated simulation trials until the observed downstream hydrograph closely matches the simulated channel outflow. All work on calibration of the SSARR method in the South Saskatchewan River basin had already been done by AEP.

The latest version of RBAT allows handling of missing data, which means that the model can handle multi-year runs with input data series from seasonal stations. For the purposes of this study, calculations for multi-year time series would proceed using the daily time step.

Reservoir net evaporation is applied on the surface area that corresponds to the average elevation per time step. Hence, RBAT requires both the elevation - area as well as the elevation - volume curves. Incremental area tables can be used (i.e. only areas that were added by raising the level of an existing natural lake). The following input data are required for naturalization of flows in the study area:

- Daily flows from all recorded flow stations up to the current date;

- End of day storage levels for Gleniffer Lake from the time the reservoir was commissioned;
- Evaporation and precipitation on a daily basis for stations located in the close proximity to the reservoirs. This data is only used in the naturalization of flows at the reservoir sites, so the closer the precipitation station to the reservoir, the better;
- Time of travel vs flow tables for all Red Deer River reaches between Gleniffer Lake and the City of Drumheller; and
- Major diversion flows between the Gleniffer Lake and the town of Drumheller will be used in the process of naturalization.
- Recorded flow data from flow monitoring stations on the Red Deer River that are available for years prior to the commissioning of the Dickson Dam were considered to be natural flows.
- Naturalized/Natural daily flow series for Red Deer above Gleniffer Reservoir (1912 to 2016) and the recorded natural flows from tributaries (i.e. Little Red Deer River, Medicine River, Blindman River, and estimated direct runoff to Red Deer River) were used to generate naturalized/natural flows at the various locations shown in Figure B2.

Figure B2: RBAT Modeling Schematic of the Red Deer River

B4.0 RELATIONSHIPS ESTABLISHED FOR RED DEER RIVER FLOWS - NATURALIZED

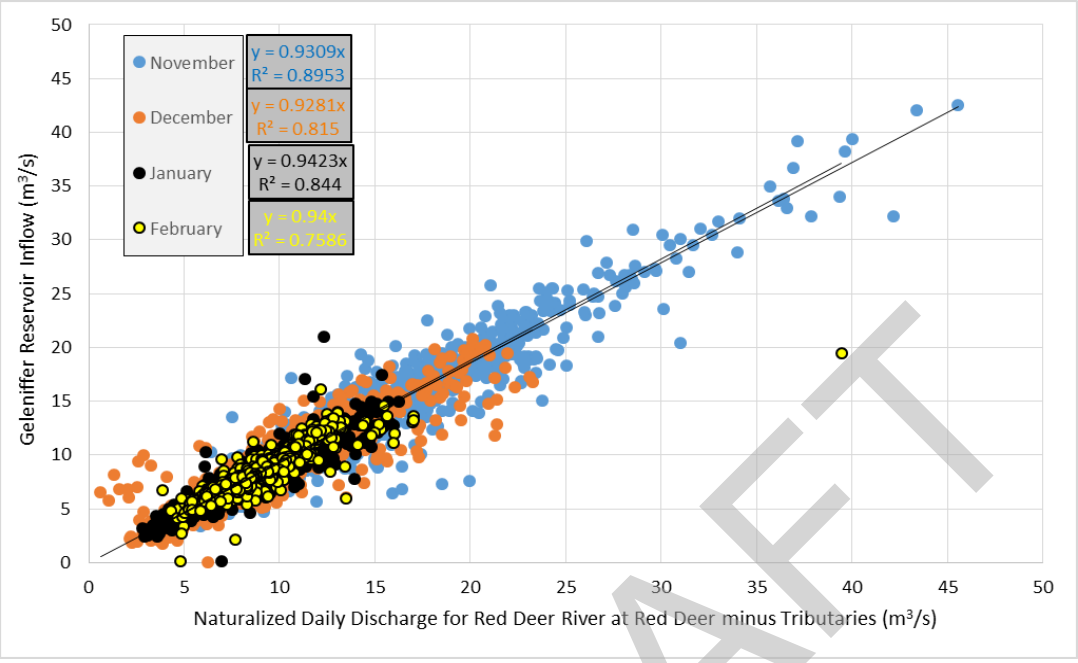


Figure B3: Relationship between the naturalized Inflow to Gleniffer Reservoir and Red Deer River at Red Deer minus the tributary flows from the Little Red Deer River near the Mouth – Winter Season

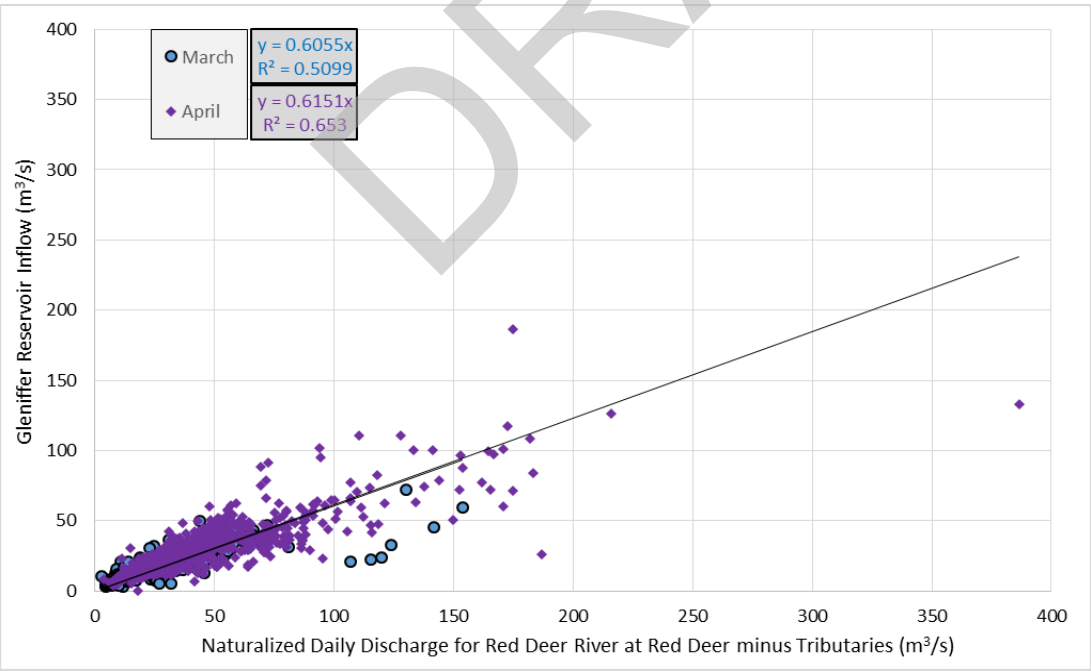


Figure B4: Relationship between the naturalized Inflow to Gleniffer Reservoir and Red Deer River at Red Deer minus the tributary flows from the Little Red Deer River near the Mouth – Early Spring Season

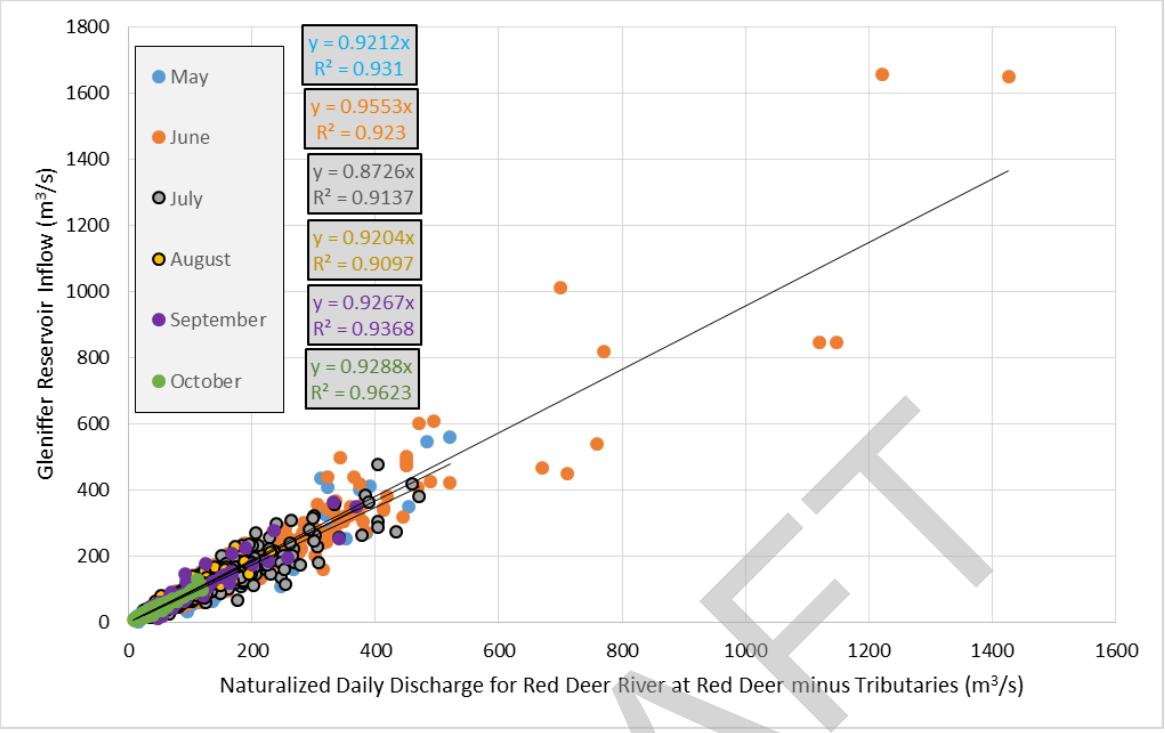


Figure B5: Relationship between the naturalized Inflow to Gleniffer Reservoir and Red Deer River at Red Deer minus the tributary flows from the Little Red Deer River near the Mouth – Open-water Season

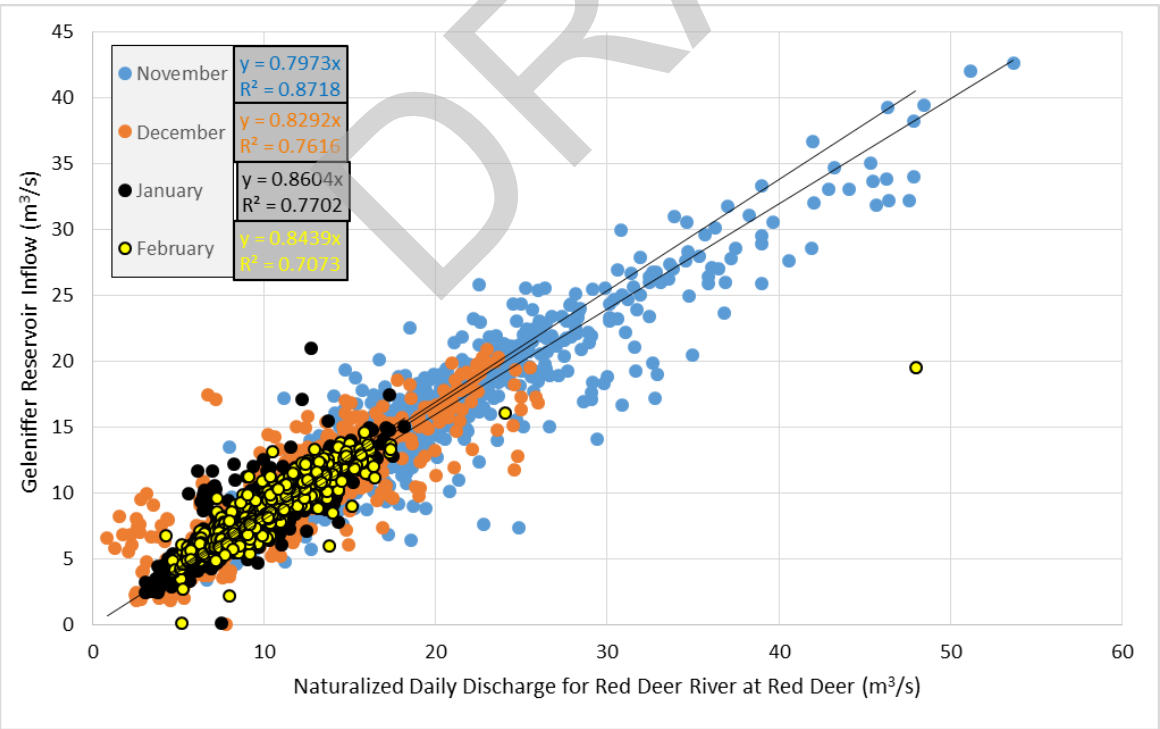


Figure B6: Relationship between the naturalized Inflow to Gleniffer Reservoir and Red Deer River at Red Deer – Winter Season

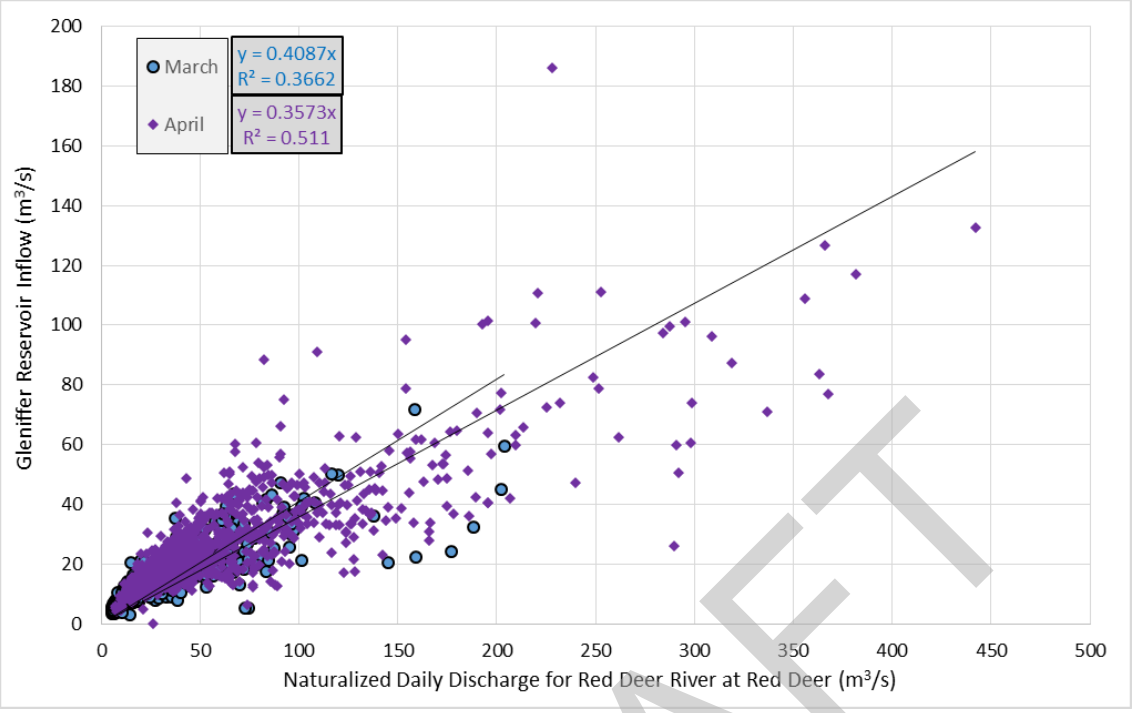


Figure B7: Relationship between the naturalized Inflow to Gleniffer Reservoir and Red Deer River at Red Deer – Early Spring Season

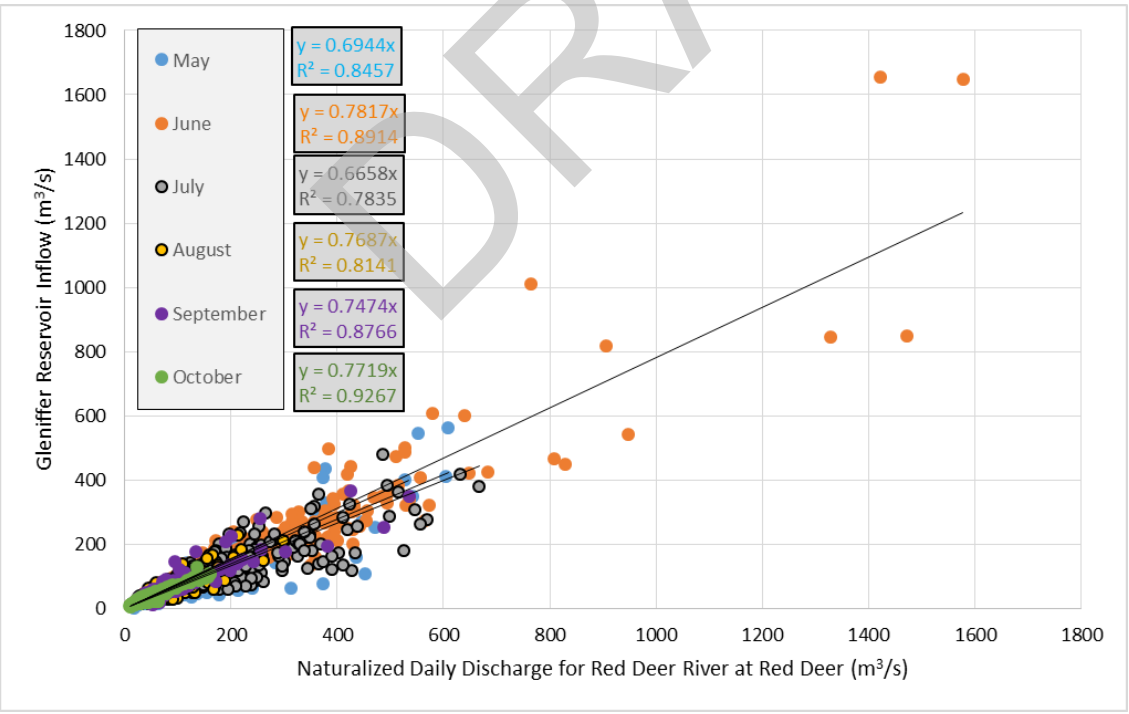


Figure B8: Relationship between the naturalized Inflow to Gleniffer Reservoir and Red Deer River at Red Deer – Open-water Season

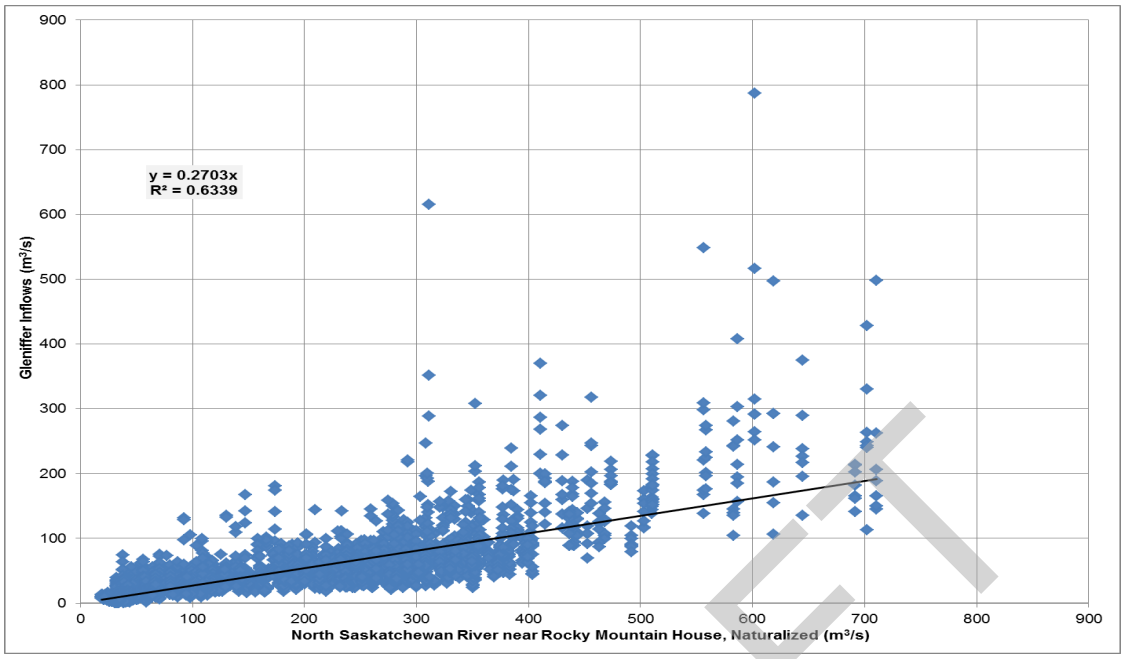


Figure B9: Relationship between the naturalized Inflow to Gleniffer Reservoir and North Saskatchewan River near Rocky Mountain House

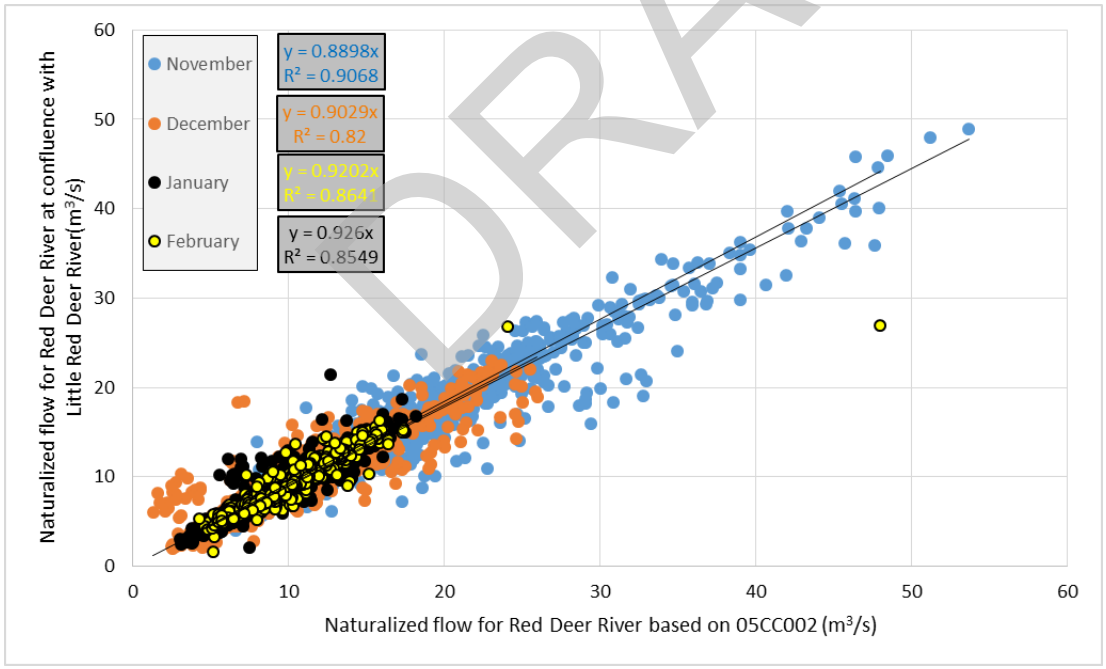


Figure B10: Relationship between the naturalized flow for Red Deer River at confluence with Little Red Deer River and Red Deer River at Red Deer – Winter Season

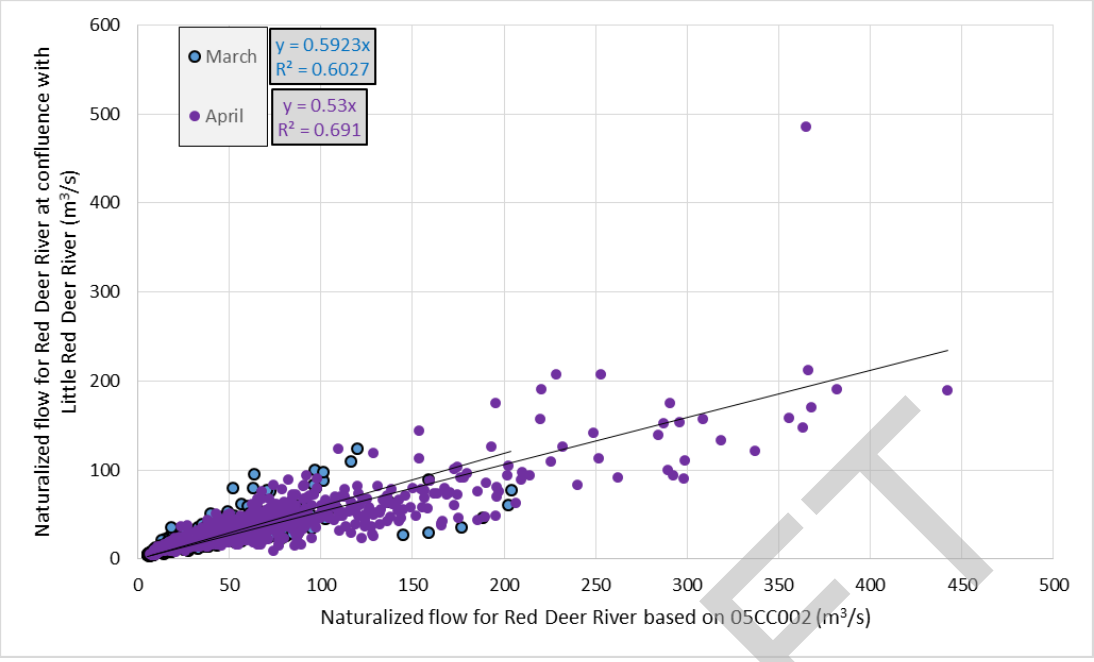


Figure B11: Relationship between the naturalized flow for Red Deer River at confluence with Little Red Deer River and Red Deer River at Red Deer – Early Spring Season

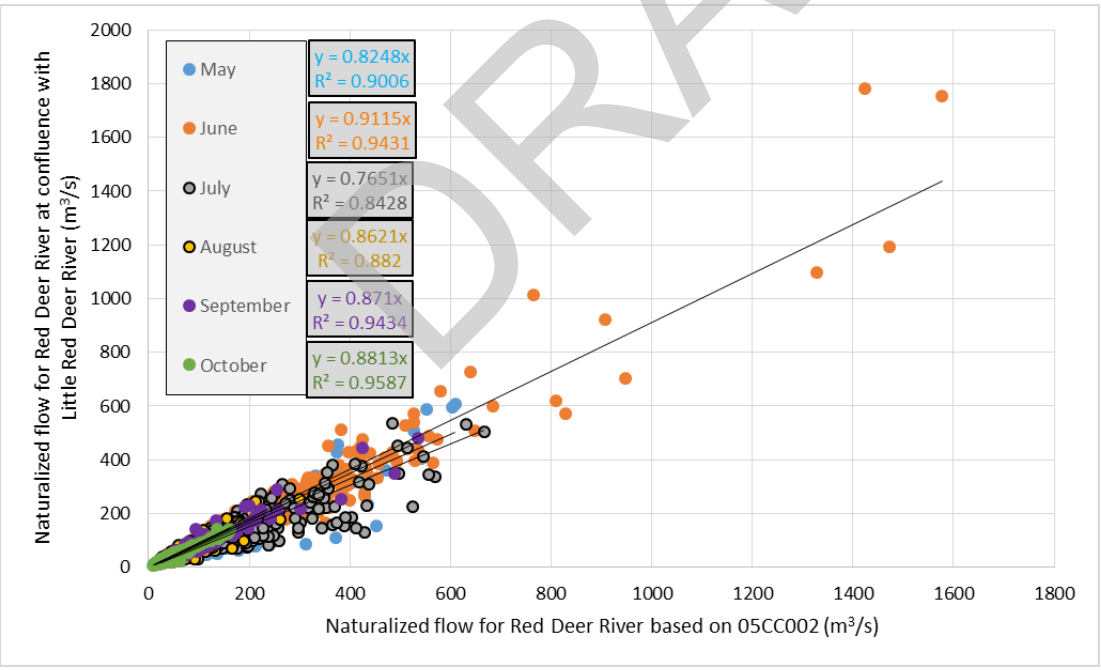


Figure B12: Relationship between the naturalized flow for Red Deer River at confluence with Little Red Deer River and Red Deer River at Red Deer – Open-water Season

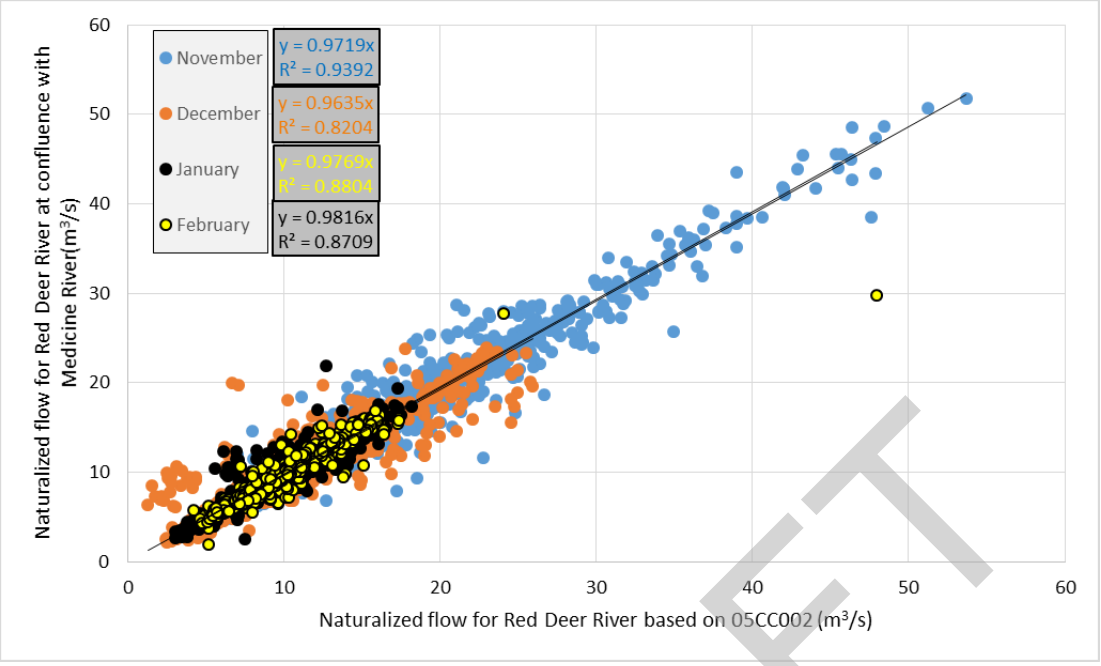


Figure B13: Relationship between the naturalized flow for Red Deer River at confluence with Medicine River and Red Deer River at Red Deer – Winter Season

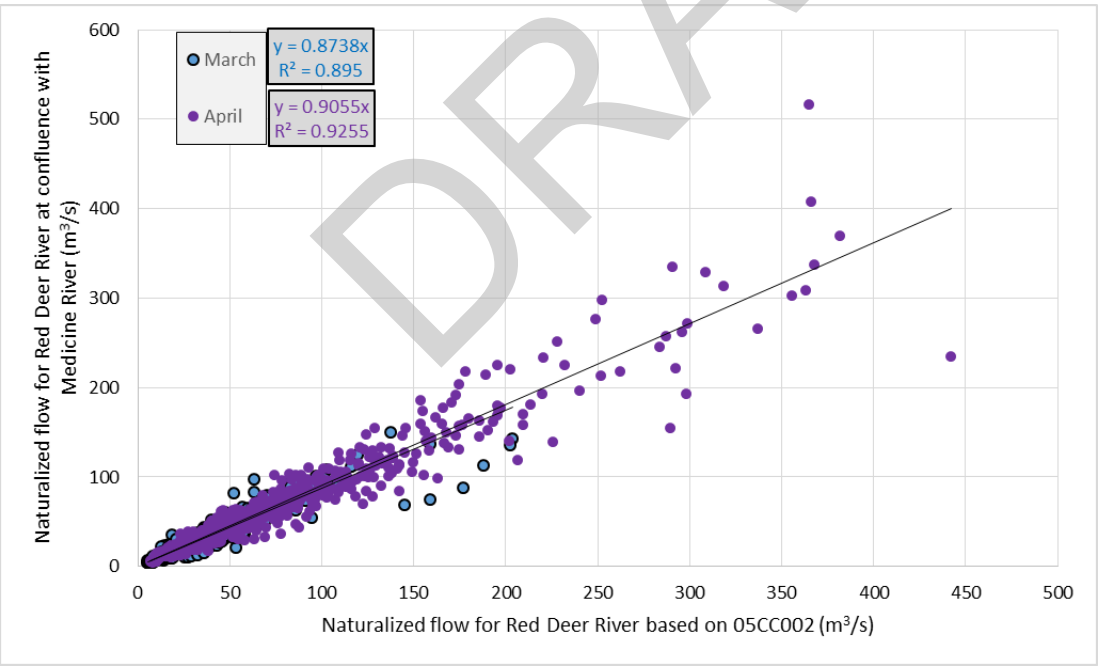


Figure B14: Relationship between the naturalized flow for Red Deer River at confluence with Medicine River and Red Deer River at Red Deer – Early Spring Season

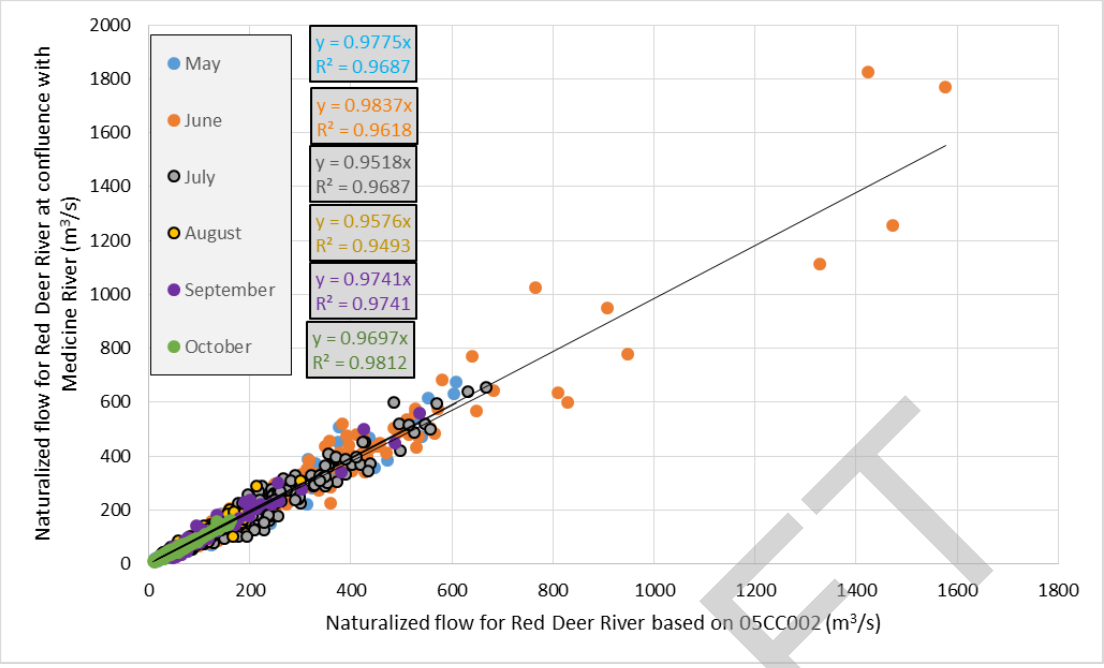


Figure B15: Relationship between the naturalized flow for Red Deer River at confluence with Medicine River and Red Deer River at Red Deer – Open-water Season

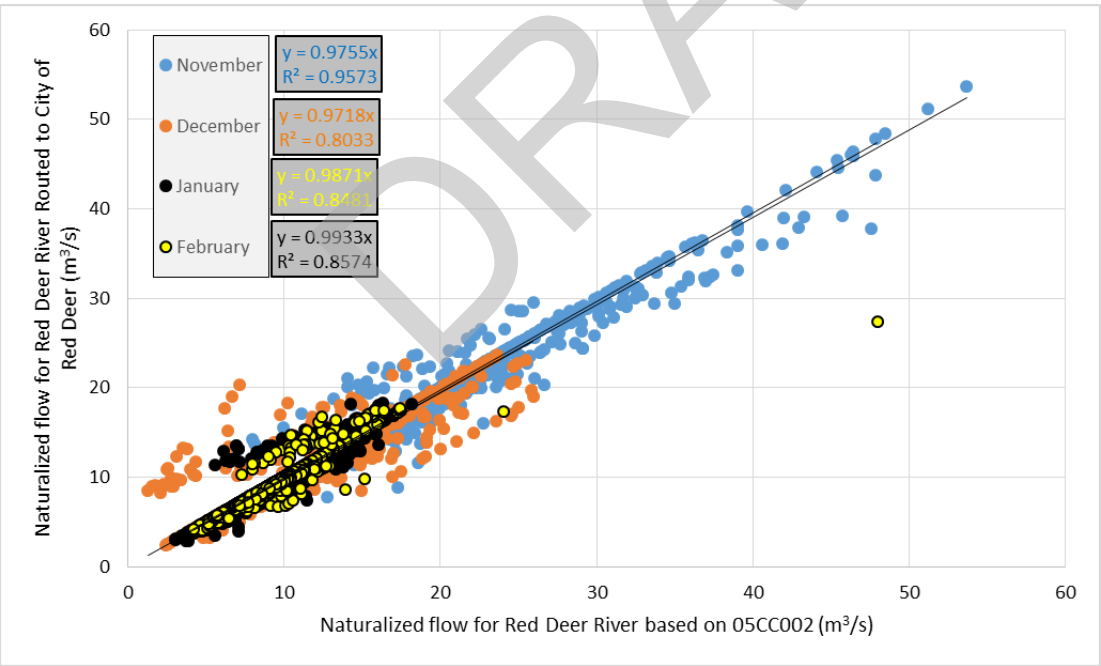


Figure B16: Relationship between the naturalized flow for Red Deer River upstream of Red Deer and Red Deer River at Red Deer – Winter Season

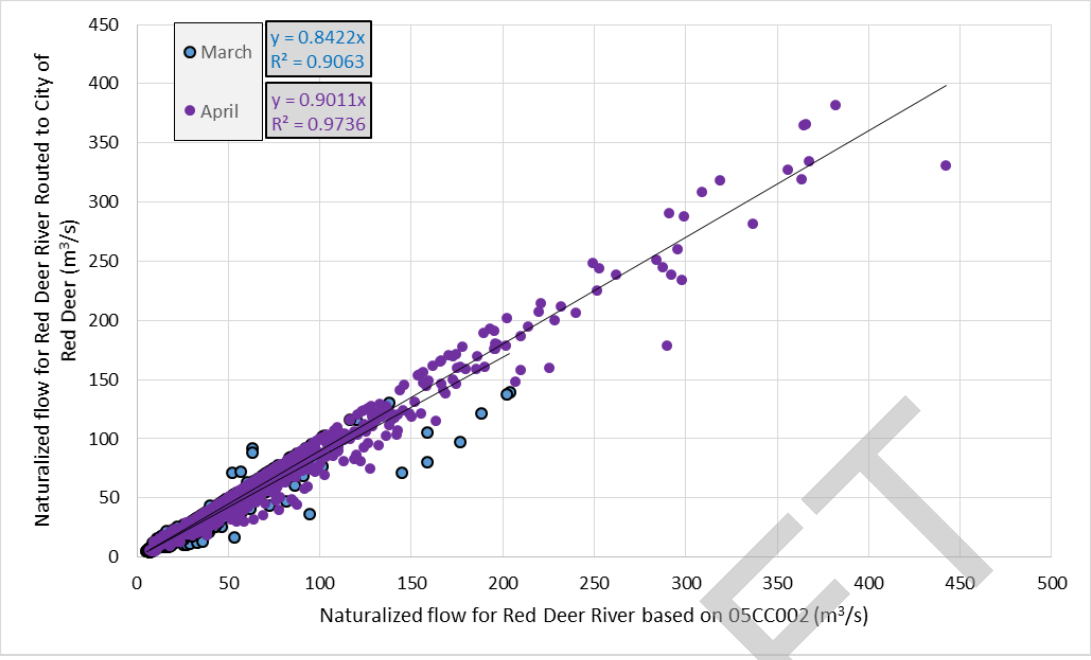


Figure B17: Relationship between the naturalized flow for Red Deer River upstream of Red Deer and Red Deer River at Red Deer – Early Spring Season

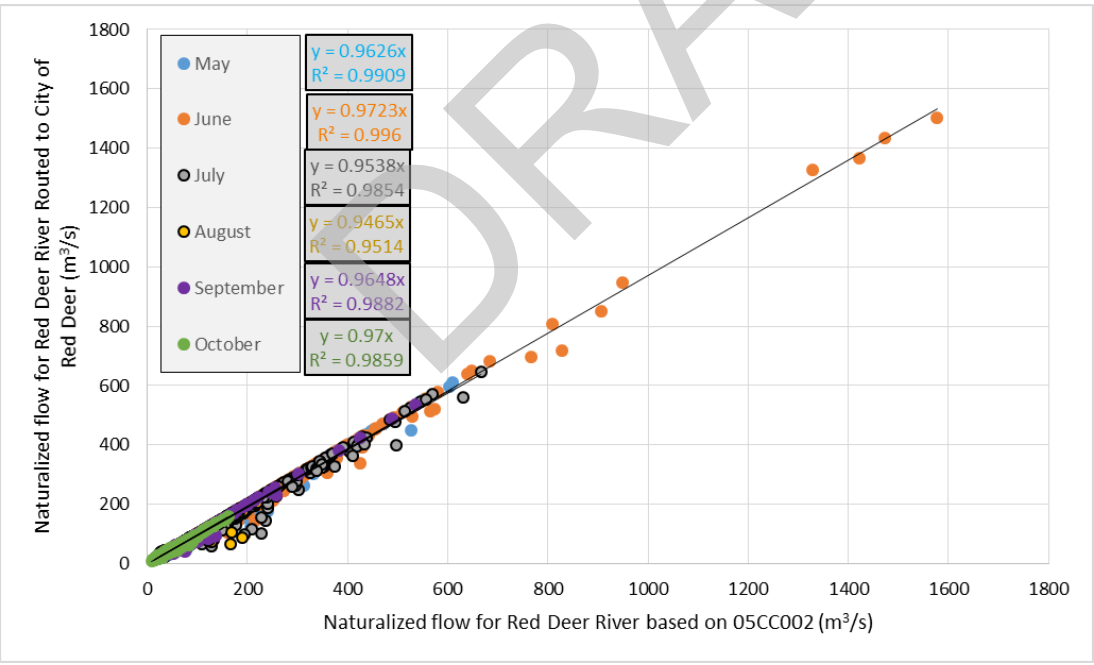


Figure B18: Relationship between the naturalized flow for Red Deer River upstream of Red Deer and Red Deer River at Red Deer – Open-water Season

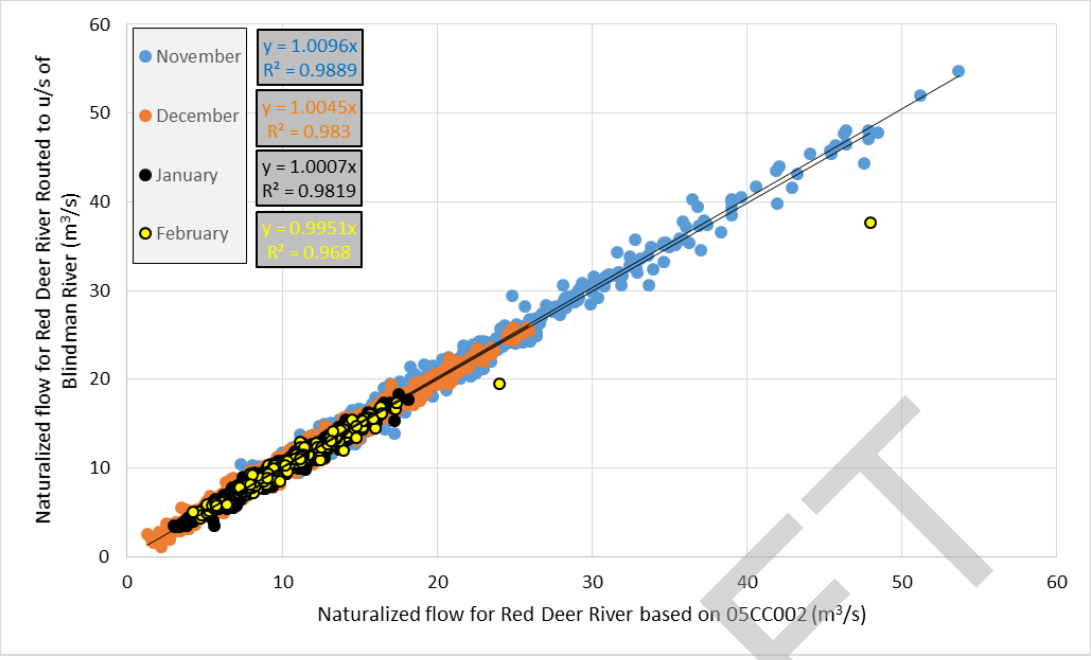


Figure B19: Relationship between the naturalized flow for Red Deer River upstream of Blindman River and Red Deer River at Red Deer – Winter Season

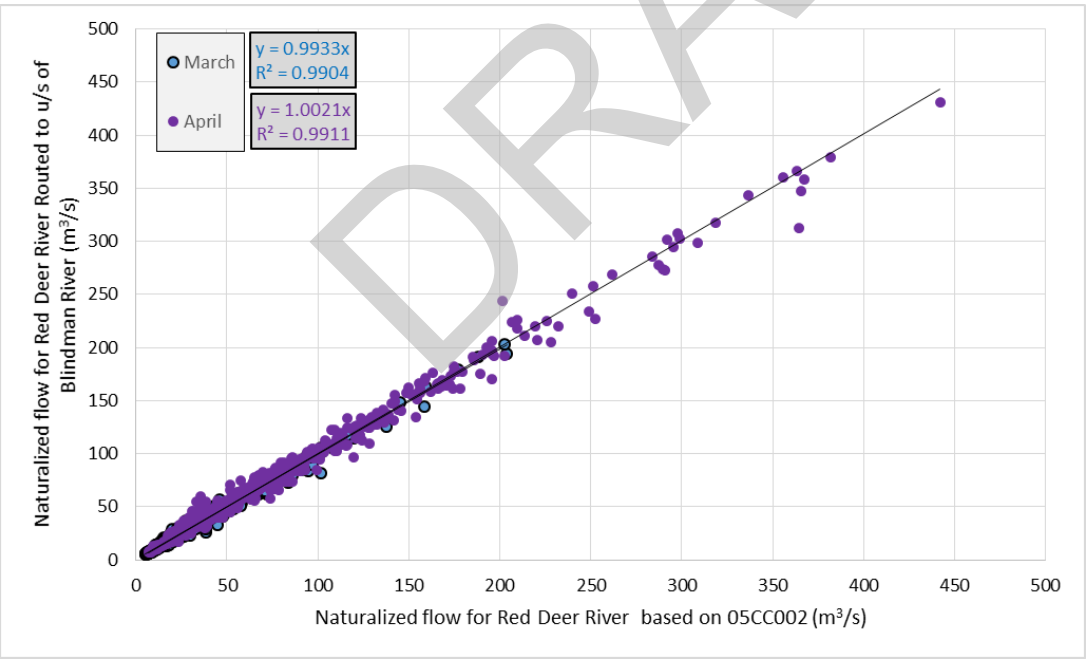


Figure B20: Relationship between the naturalized flow for Red Deer River upstream of Blindman River and Red Deer River at Red Deer – Early Spring Season

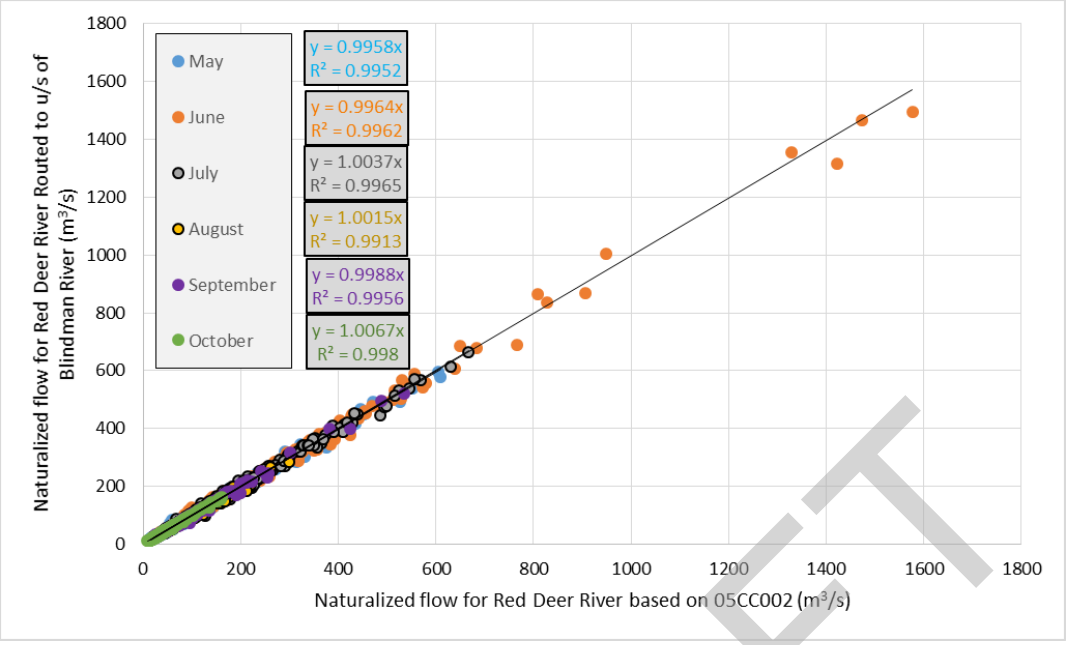


Figure B21: Relationship between the naturalized flow for Red Deer River upstream of Blindman River and Red Deer River at Red Deer – Open-water Season

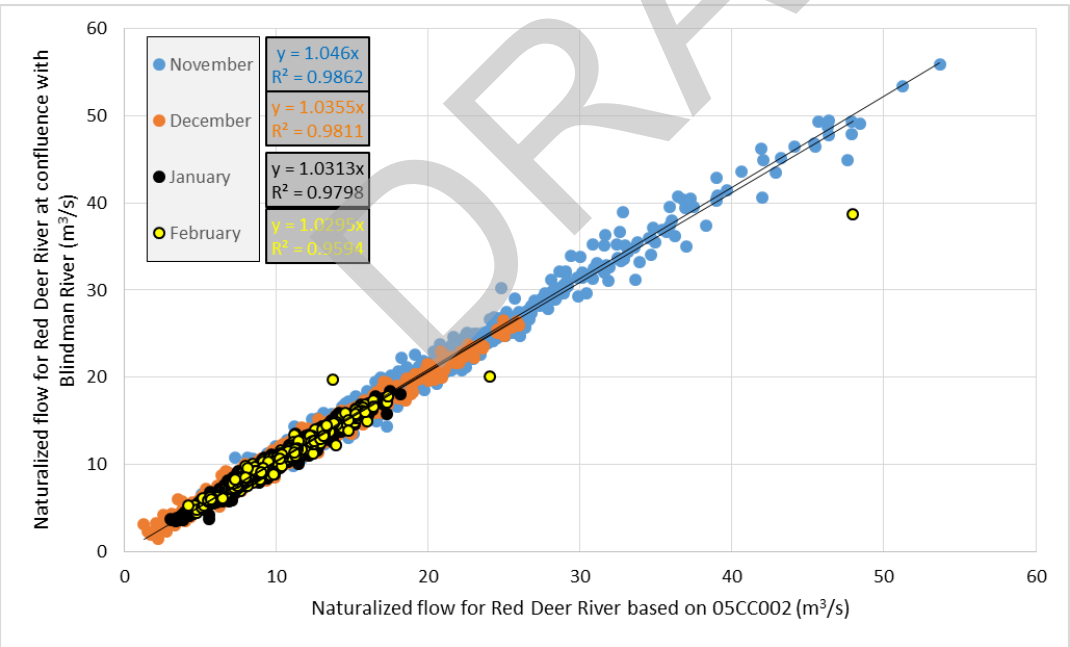


Figure B22: Relationship between the naturalized flow for Red Deer River downstream of Blindman River and Red Deer River at Red Deer – Winter Season

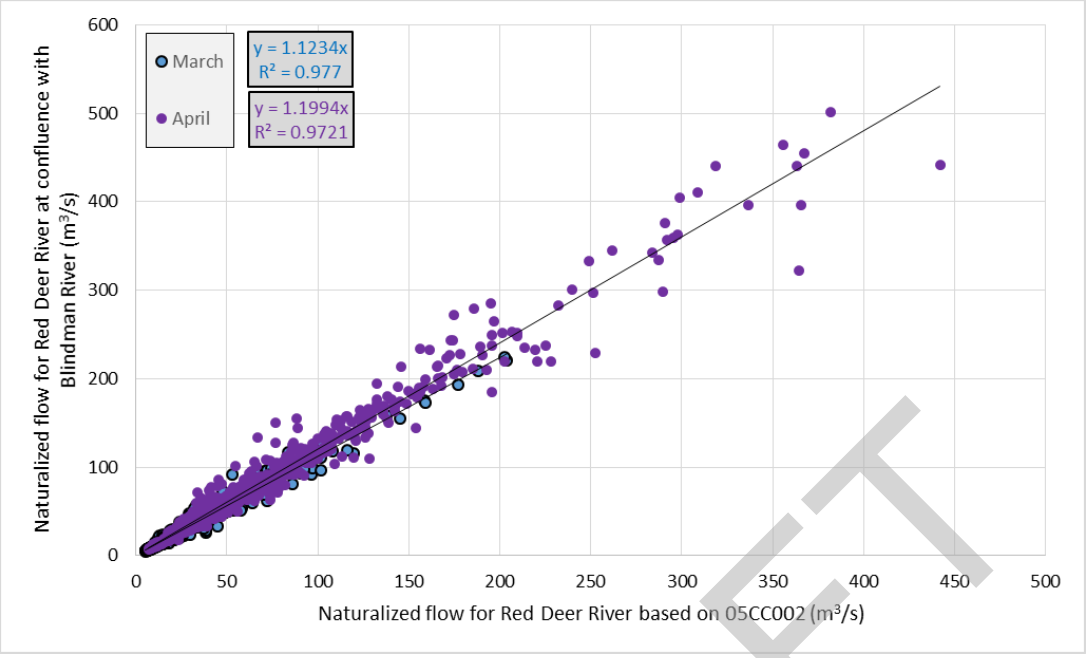


Figure B23: Relationship between the naturalized flow for Red Deer River downstream of Blindman River and Red Deer River at Red Deer – Early Spring Season

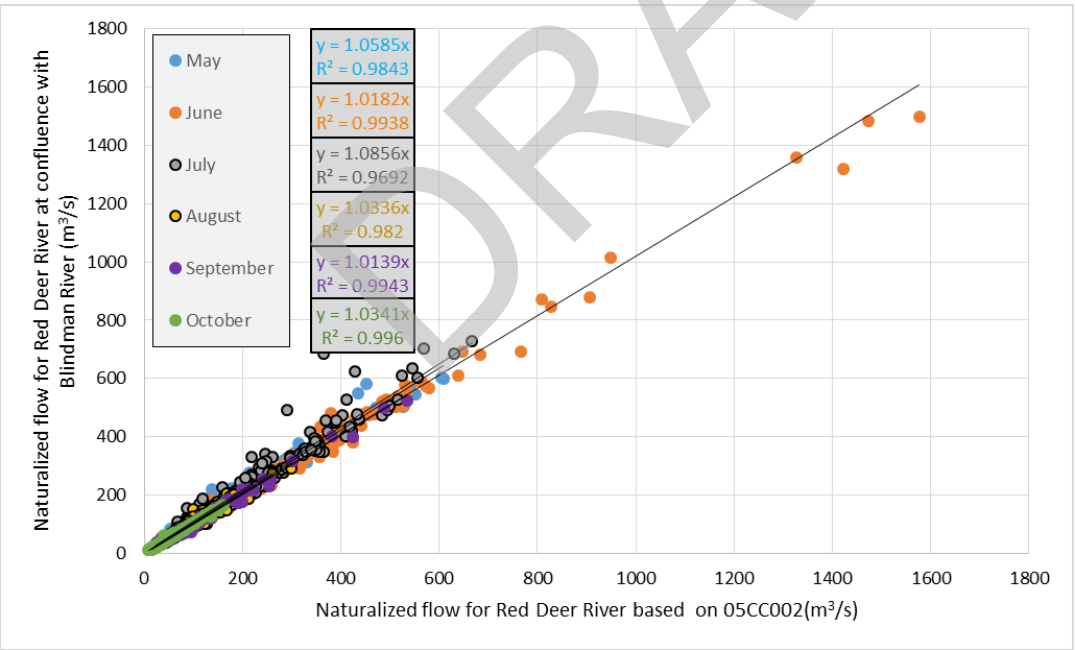


Figure B24: Relationship between the naturalized flow for Red Deer River downstream of Blindman River and Red Deer River at Red Deer – Open-water Season

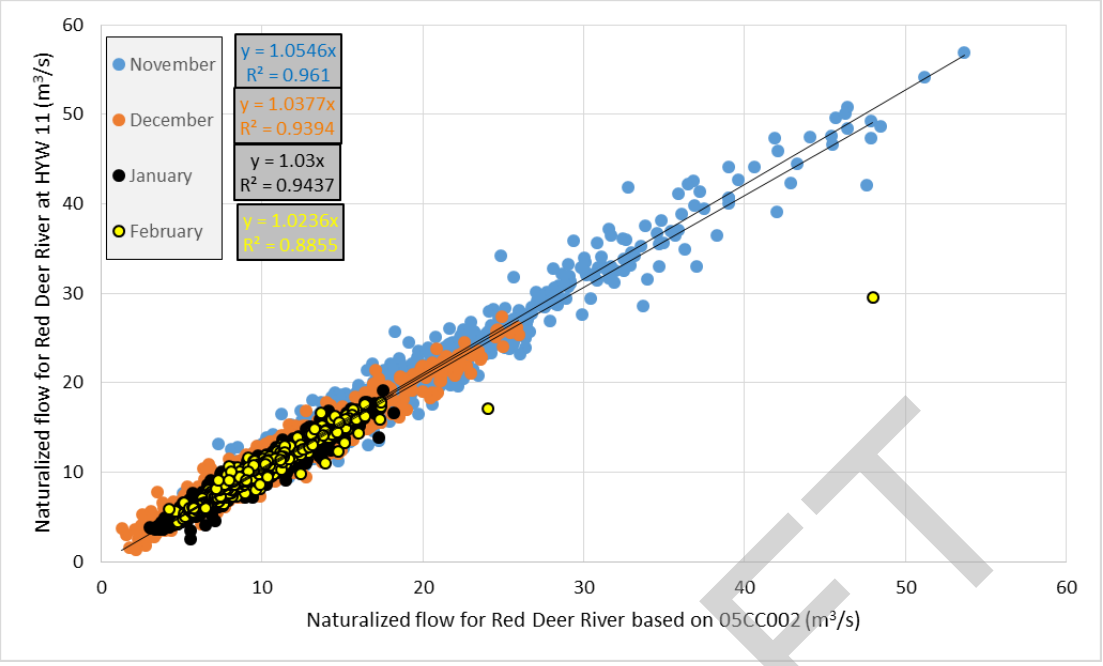


Figure B25: Relationship between the naturalized flow for Red Deer River at Highway 11 and Red Deer River at Red Deer – Winter Season

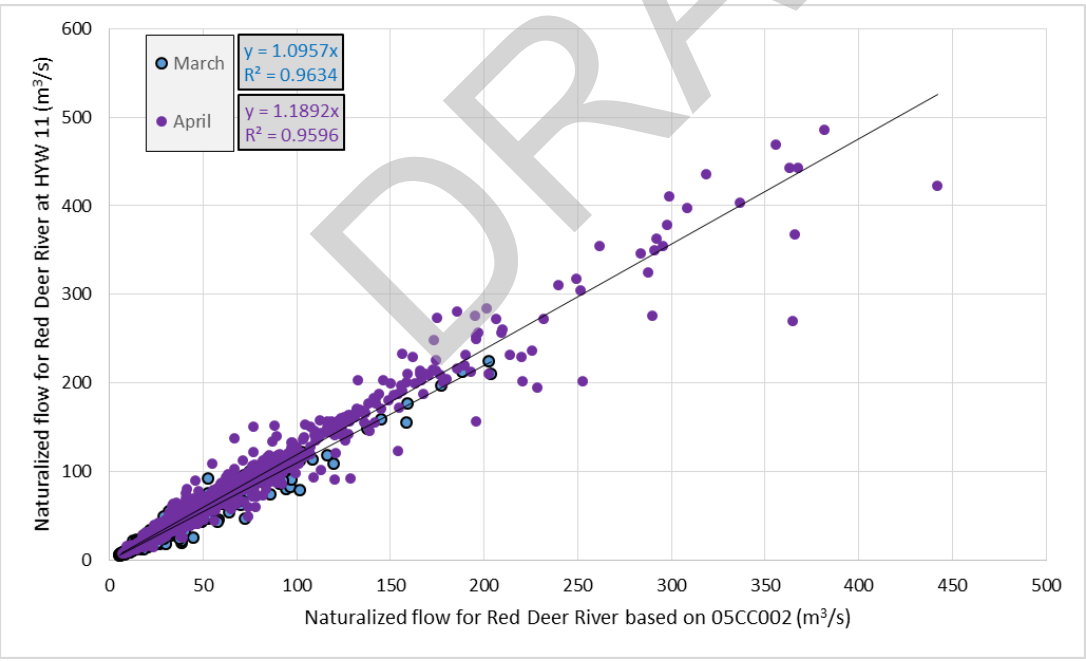


Figure B26: Relationship between the naturalized flow for Red Deer River at Highway 11 and Red Deer River at Red Deer – Early Spring Season

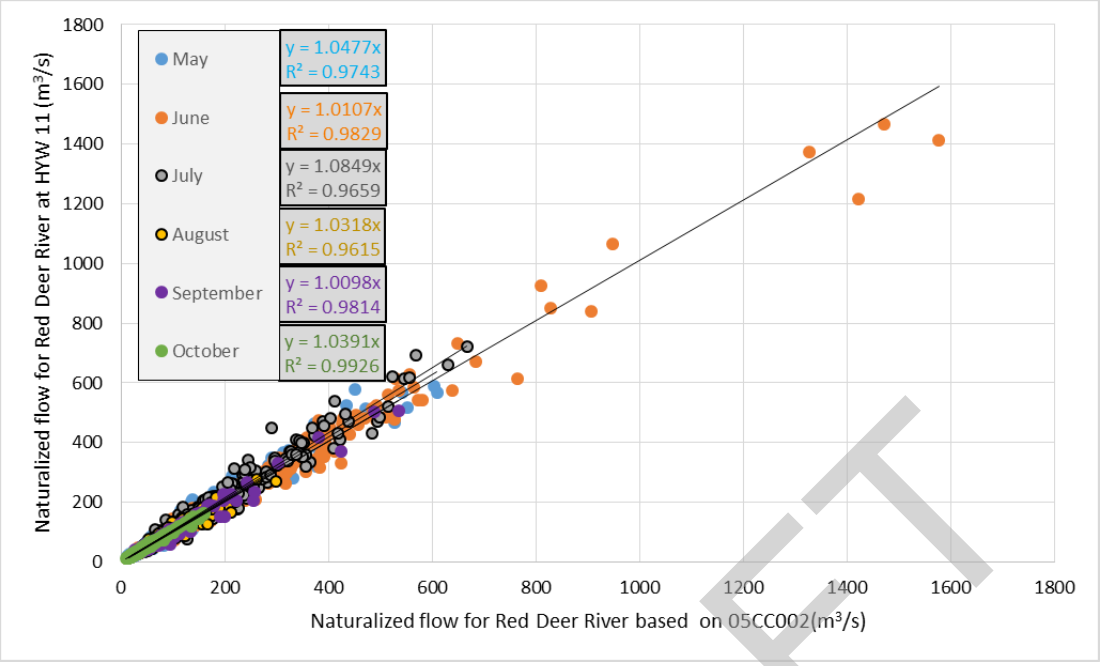


Figure B27: Relationship between the naturalized flow for Red Deer River at Highway 11 and Red Deer River at Red Deer – Open-water Season

B5.0 RELATIONSHIPS ESTABLISHED FOR RED DEER RIVER FLOWS - REGULATED

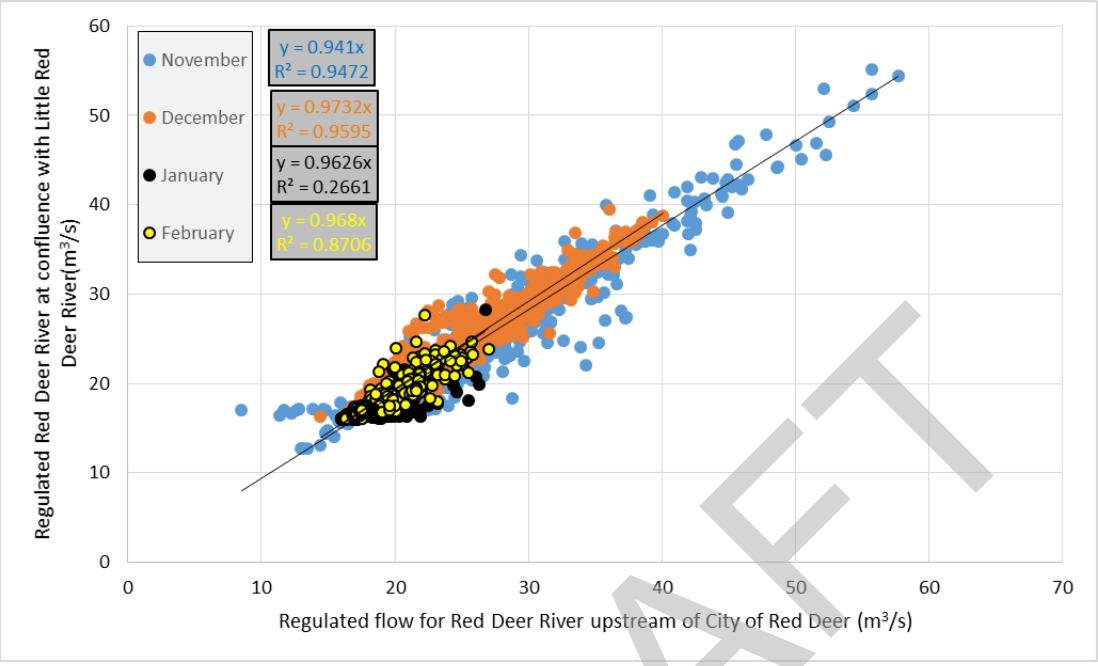


Figure B28: Relationship between the regulated flow for Red Deer River at confluence with Little Red Deer River and Red Deer River at Red Deer – Winter Season

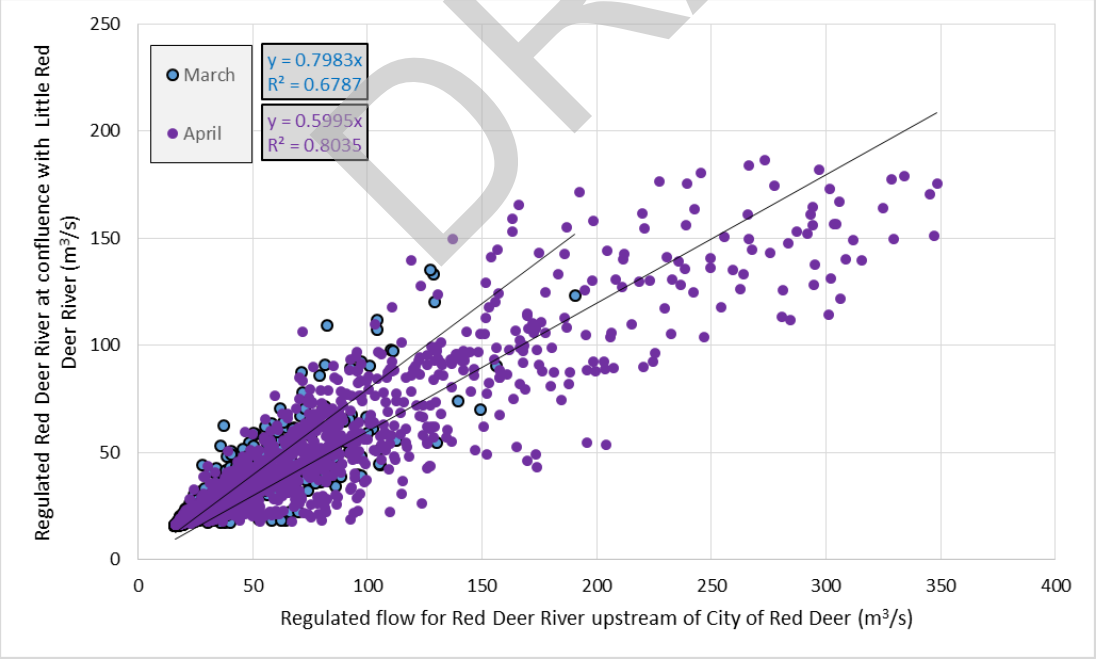


Figure B29: Relationship between the regulated flow for Red Deer River at confluence with Little Red Deer River and Red Deer River at Red Deer – Early Spring Season

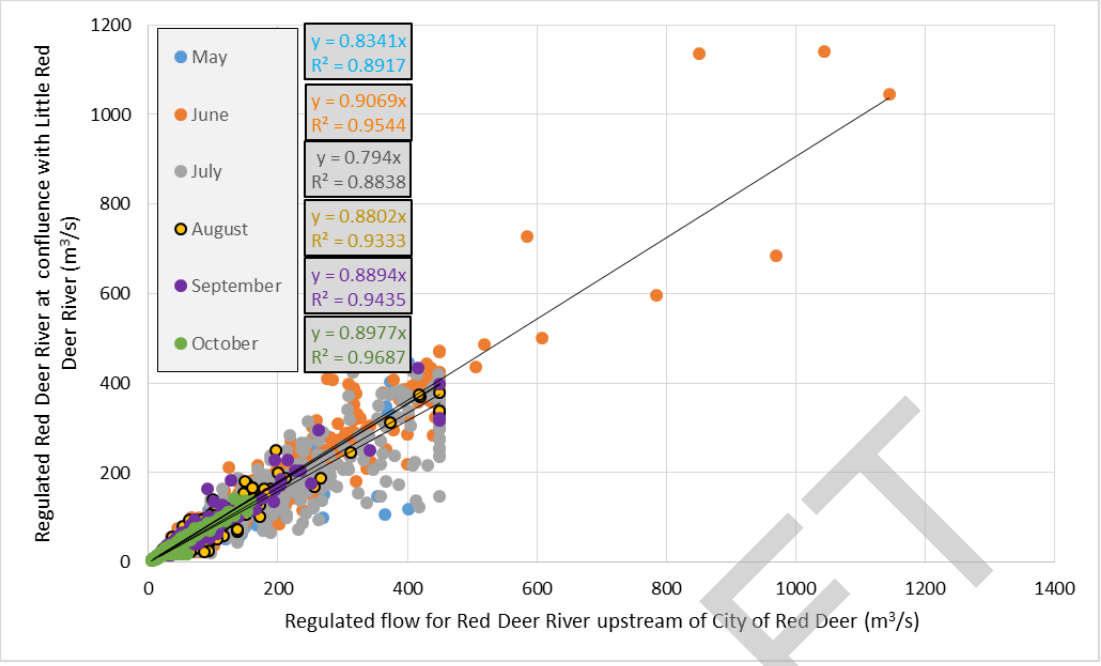


Figure B30: Relationship between the regulated flow for Red Deer River at confluence with Little Red Deer River and Red Deer River at Red Deer – Open-water Season

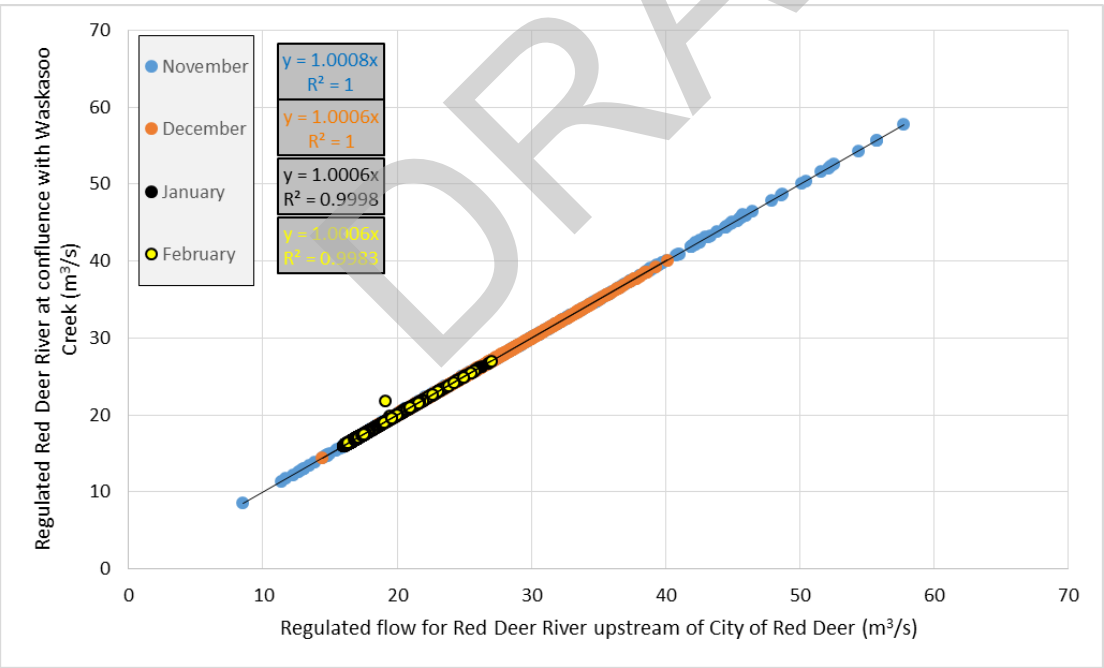


Figure B31: Relationship between the regulated flow for Red Deer River upstream of Blindman River and Red Deer River at Red Deer – Winter Season

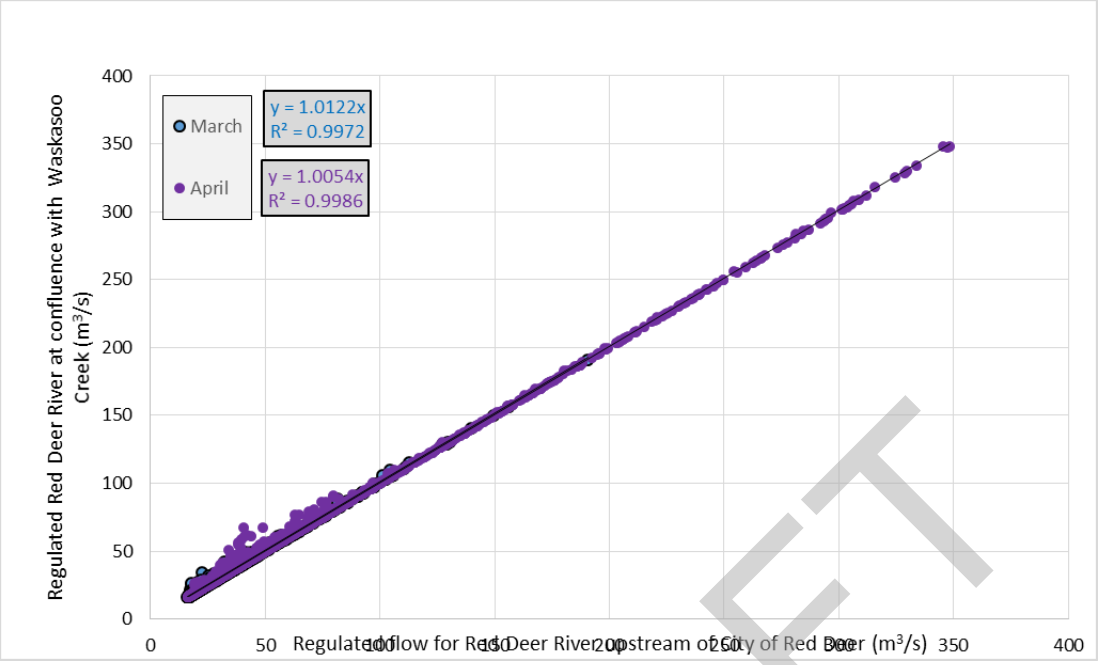


Figure B32: Relationship between the regulated flow for Red Deer River upstream of Blindman River and Red Deer River at Red Deer – Early Spring Season

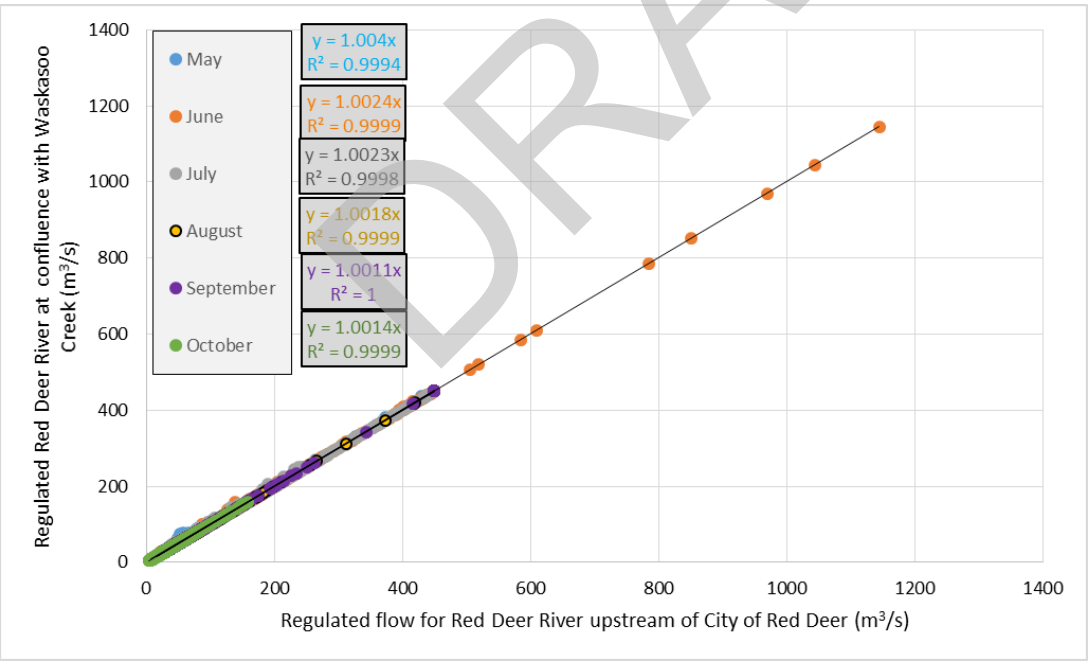


Figure B33: Relationship between the regulated flow for Red Deer River upstream of Blindman River and Red Deer River at Red Deer – Open-water Season

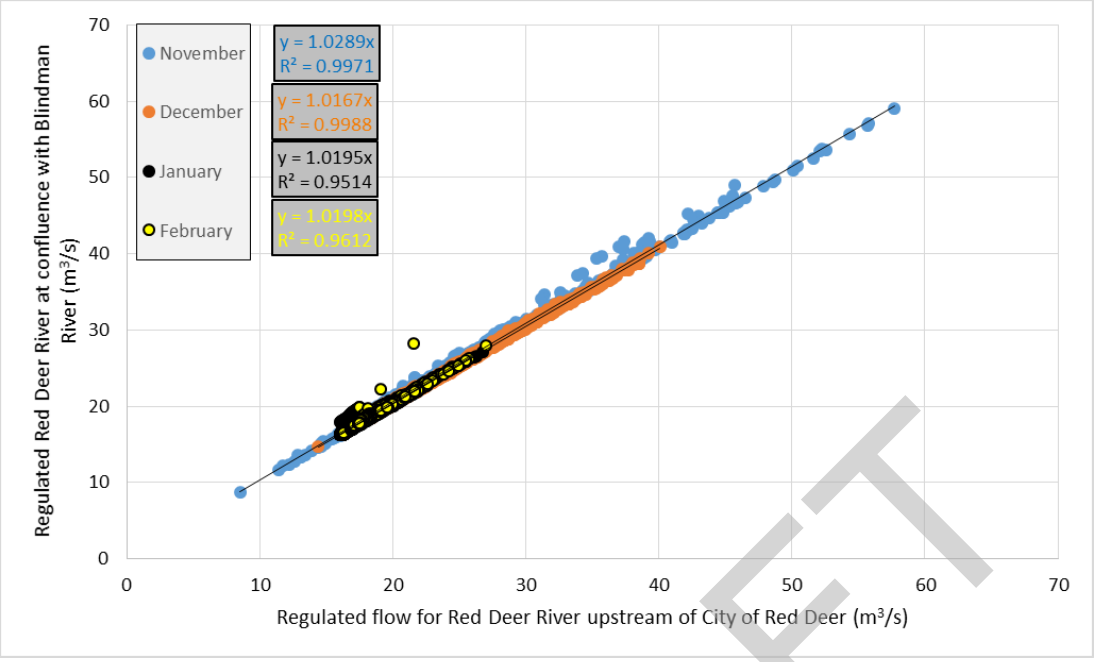


Figure B34: Relationship between the regulated flow for Red Deer River downstream of Blindman River and Red Deer River at Red Deer – Winter Season

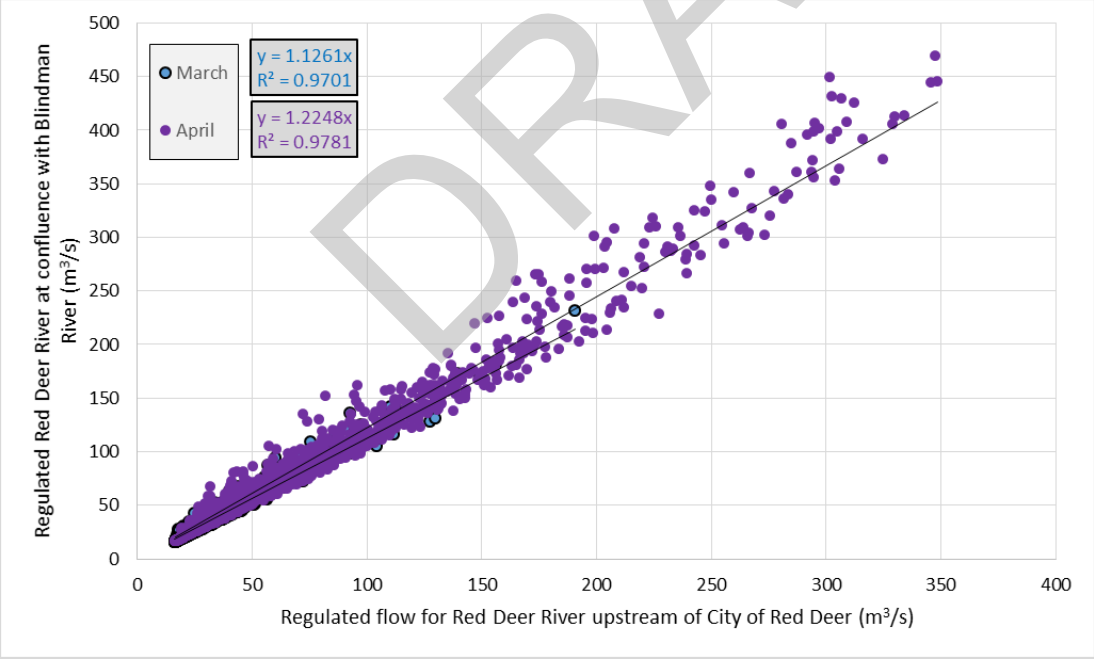


Figure B35: Relationship between the regulated flow for Red Deer River downstream of Blindman River and Red Deer River at Red Deer – Early Spring Season

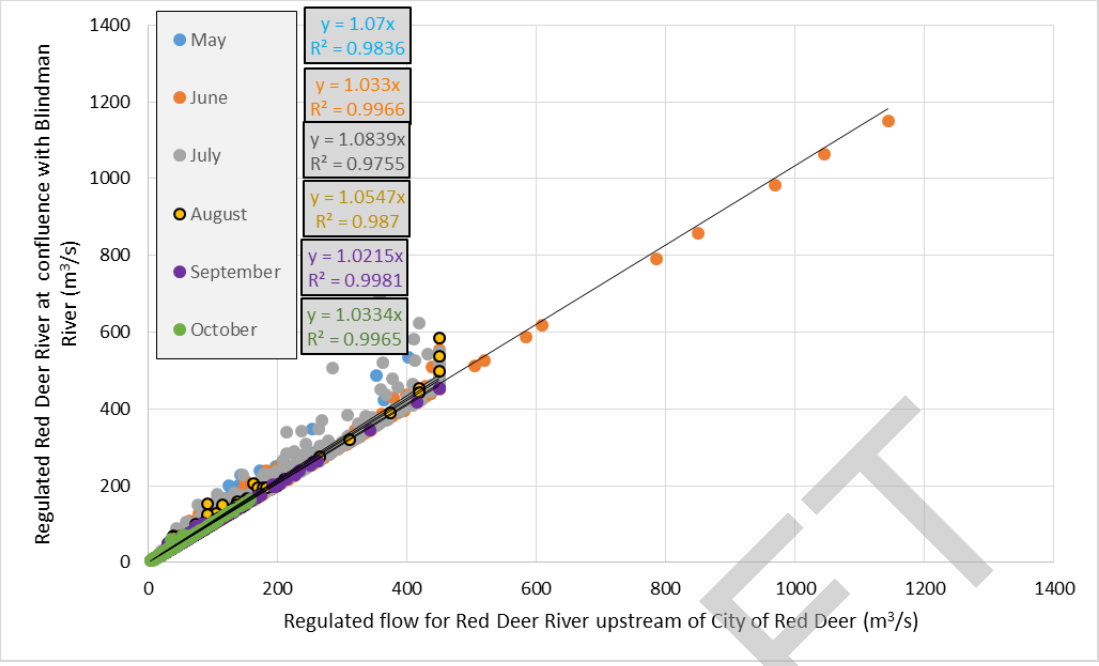


Figure B36: Relationship between the regulated flow for Red Deer River downstream of Blindman River and Red Deer River at Red Deer – Open-water Season

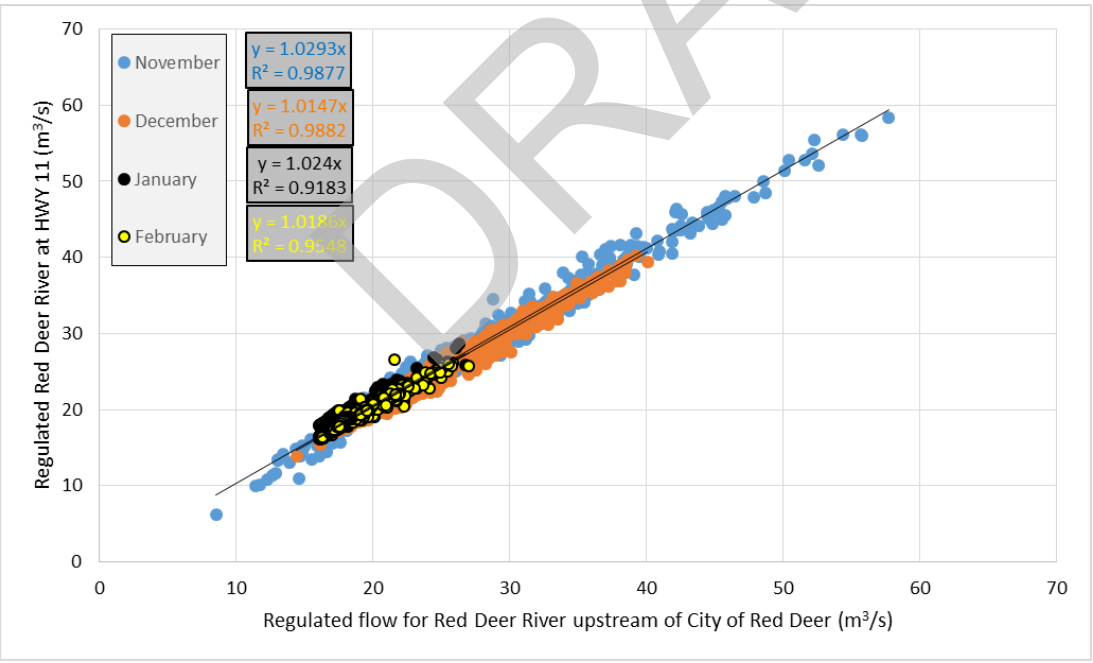


Figure B37: Relationship between the regulated flow for Red Deer River at Highway 11 and Red Deer River at Red Deer – Winter Season

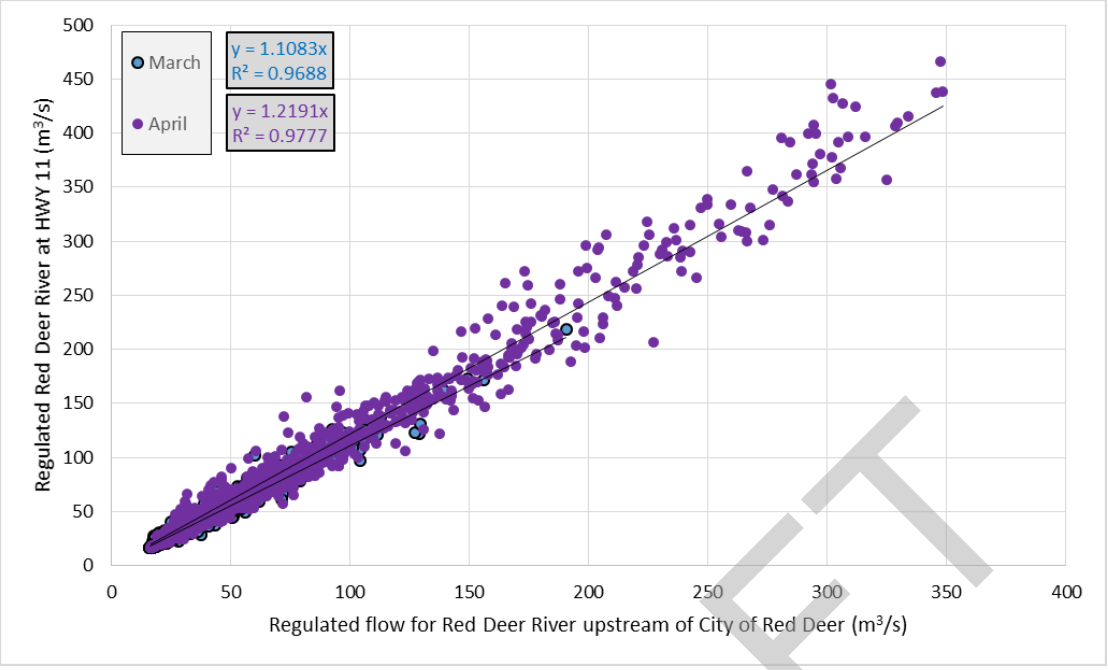


Figure B38: Relationship between the regulated flow for Red Deer River at Highway 11 and Red Deer River at Red Deer – Early Spring Season

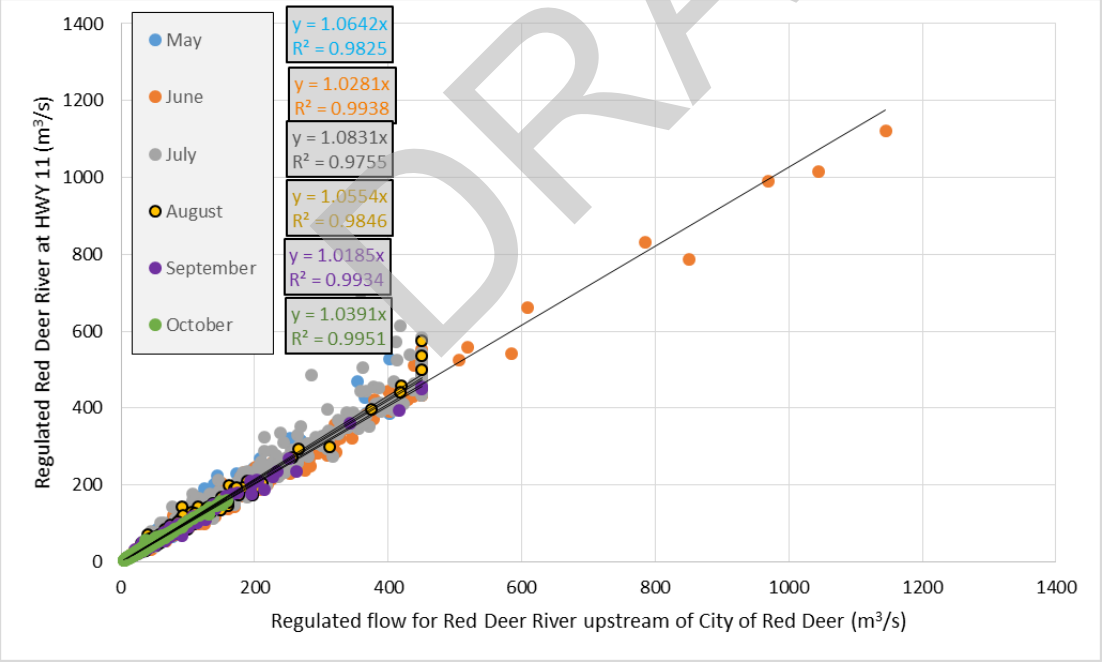


Figure B39: Relationship between the regulated flow for Red Deer River at Highway 11 and Red Deer River at Red Deer – Open-water Season

B6.0 DICKSON DAM OPERATION RULES

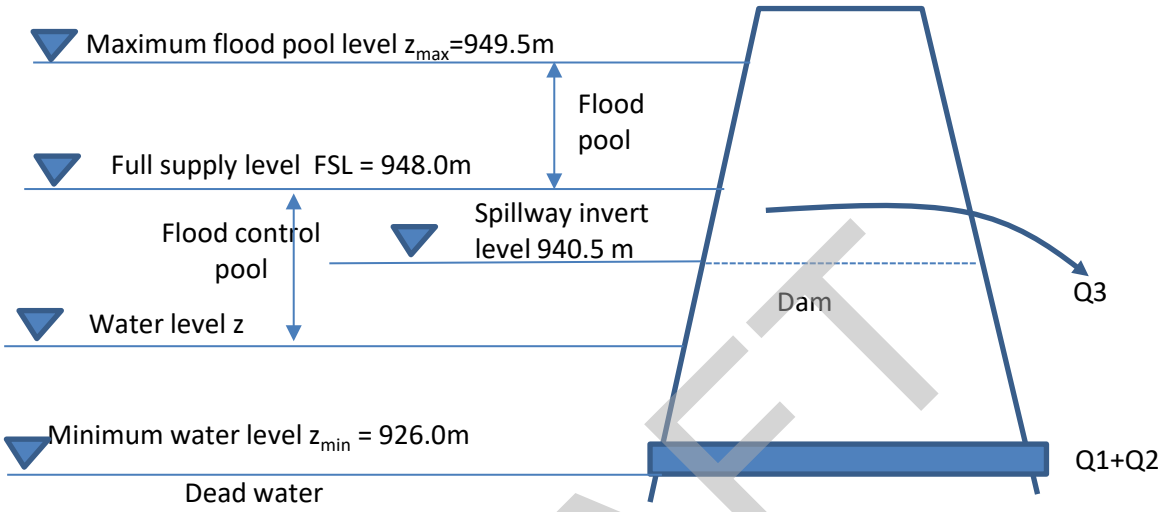


Figure B10 – Sketch of control water levels

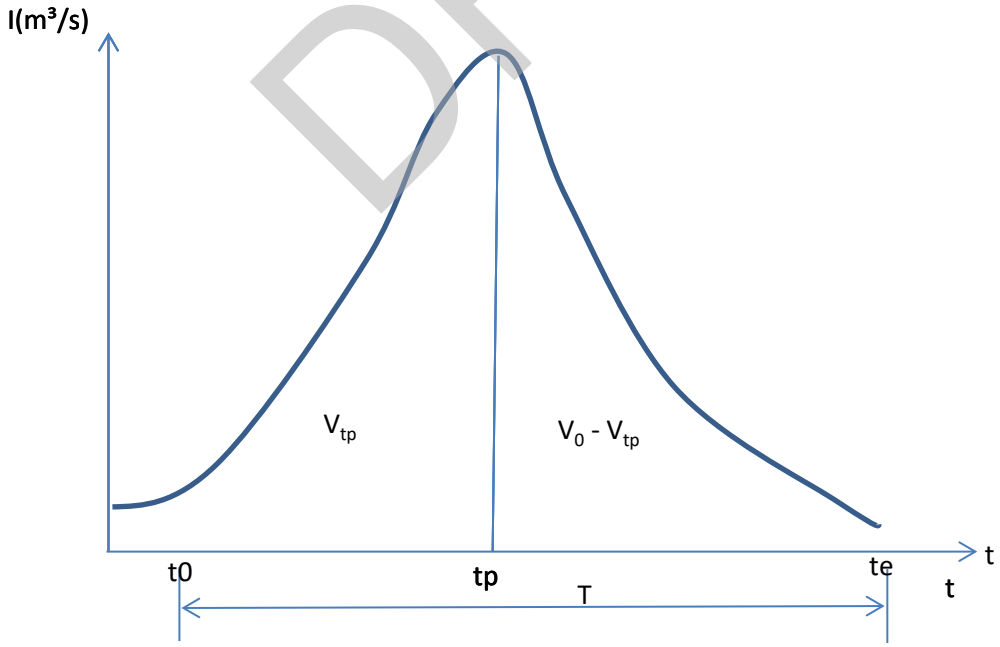


Figure B11 – Sketch of Typical inflow hydrograph

Definitions of Parameters:

FSL – full supply water level, FSL = 948.0 m
I – Inflow rate
NOL –input normal operation level, NOL ranges from 940.5m to 948m
Q_{out} – outflow rate
Q_{max} – Reservoir outflow capacity, Q_{max} = 60m³/s + spillway capacity
Q_{pr} – pre-release flow rate
t – Time
T – Duration of flood event, T = t_e – t_0
t_0 – flood even start time
t_e – flood event ending time
tp –peak inflow arrival time
Z_{max} – allowable maximum water level, z_{max} = 949.5m
Although this is the top of the "flood pool", this is only used as an emergency buffer. Typically the dam is not operated above FSL in a high flow event.
Z_{min} – lake minimum water level, z_{min} = 926.0m
Δt – time step

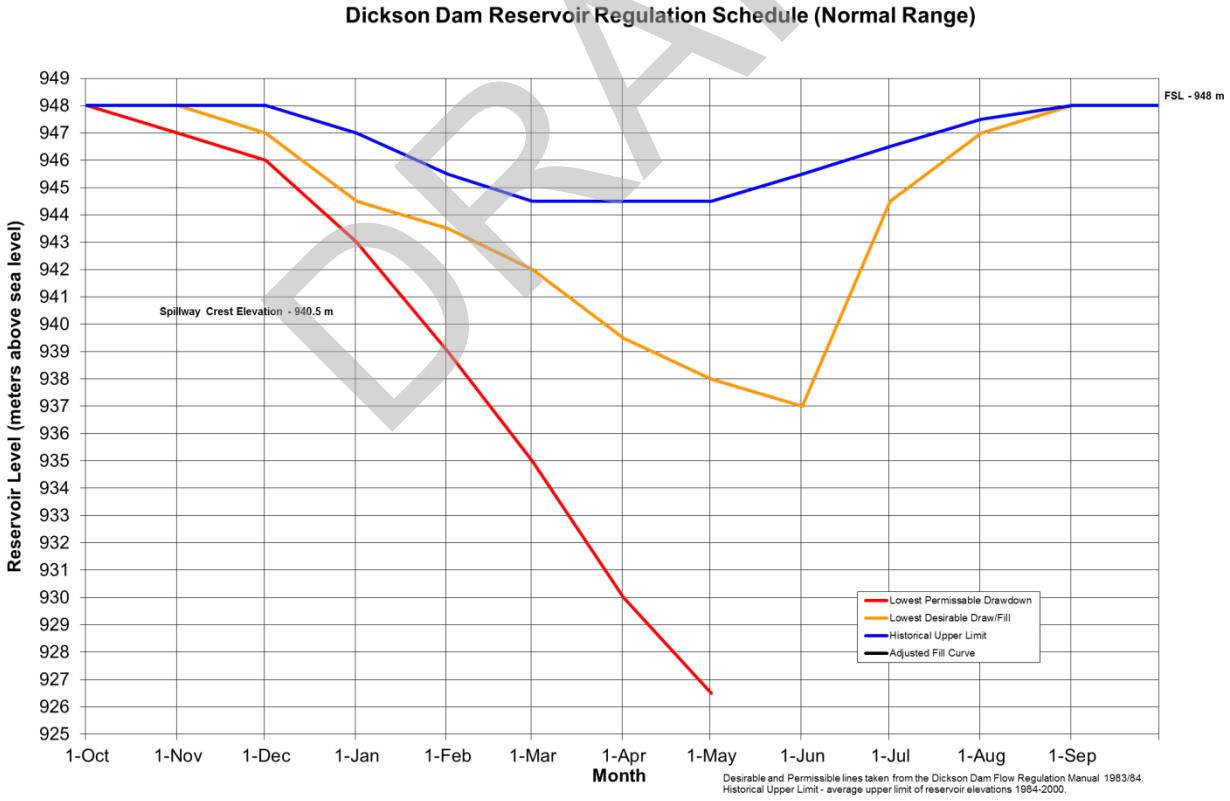
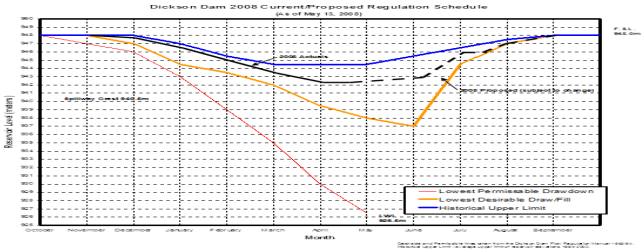


Table B1: Reservoir Operation Rule during Flood Inflow

Definition	Mathematical Description
1. Reservoir water level before and after flood should be at Normal Operating Level **(NOL)** for the season – **Input as starting water level** 	**Z=NOL at t=o and t ≥ T;** where, t is time during flood and T is the total period of current inflow flood. Z – Water level at time t
2. Combined flow through the two Diversion Tunnels not exceed 100 m^3/s (40 m^3/s through Tunnel #1 and 60 m^3/s through the Hydropower Tunnel). If outflow through the spillways occurred, set flow through Tunnel #1 to zero.	Q_{max} = 60 m^3/s + Spillway Capacity
3. Outflow should be less than or equal to inflow during rising of flood hydrograph Optimum outflow discharge will be determined based on optimization of the use of storage in the flood control pool.	$Q_{out} \leq$ min(Inflow, Q_{max}) ; for Inflow>Q_{pr} and t≤ t_p
4. Based on pre-release guideline, sometime the operator may decide to pre-release flow from the reservoir, if extreme flood is forecasted to create additional storage for flood. For this case, outflow from the reservoir can be increased to a maximum of 350 m^3/s (often limited by reservoir elevation) until the period when inflow flood exceeds 350 m^3/s. After the inflow flood exceed 350 m^3/s, increase the outflow to a value close to inflow. A total flow value of 450 m^3/s including any pre-release from the dam and flows from the Little Red and Medicine rivers should not be exceeded under pre-release conditions. The rate Increase in releases to the downstream channel must be gradual and should be according to the following reservoir operation rules: **Current Release (m^3/s) / Maximum Rate of Increase (m^3/s/hour)** 16-50 / 30 50-100 / 50 >100 / 70	Q_{out} = Q_{pr} ; for <u>Inflow < Q_{pr}</u> and <u>t≤ t_p:</u> $Q_{pr} \leq$ 350 m^3/s Q_{pr} – pre-release outflow determined according operation rules
5. After peak inflow, if reservoir elevation in the flood pool region (i.e., the reservoir level is greater than 948.0), operators will match outflows to inflows as per the Flood Operating Procedures.	Q_{out} = min (Q_{out} @ tp, Q_{max}); When t > t_p and Z > FSL Q_{max} – Maximum outflow capacity at current water level.
6. During recession of flood, if the reservoir level dropped back to NOL, outflow should be equal to current inflow.	Q_{out} Inflow; if Z = NOL & t ≥ t_p t_p – time to peak inflow Q_{out} = Q1 + Q2 + Q3
7. Decrease in the reservoir level should be according to the following reservoir operation rules: **Maximum Reservoir Drawdown Rates** **Reservoir Elevation (m) / Rate (cm/hour)** 948.0 - 944.0 / 4.2 944.0 - 940.0 / 2.1 940.0 - 926.0 / 1.3	**<u>For t >t_p :</u>** DZ ≥ -4.2 cm/hr if Z e [944,948] DZ ≥ -2.1 cm/hr if Z e[940,944) DZ ≥ -1.3 cm/hr if Z e[926,940)

From: Shoma Tanzeeba [mailto:shoma.tanzeeba@gov.ab.ca]
Sent: Friday, March 18, 2016 4:43 PM
To: Biftu, Getu <Getu_Biftu@golder.com>
Cc: Khaled Akhtar <Khaled.Akhtar@gov.ab.ca>
Subject: RE: Travel Times in the Red Deer River basin

Hi Getu,

I compared the table that you have provided with the tables we have in the Hydstra model and they exactly match.
Have a great weekend.

Regards,
Shoma

Shoma Tanzeeba, M.Sc., P.Eng.
Regional Hydrologist, South Saskatchewan Region
Alberta Environment and Parks
Deerfoot Square Building
2938 - 11 Street NE
Calgary, AB, T2E 7L7
Tel. (403) 297-6462
Fax (403) 297-6069
shoma.tanzeeba@gov.ab.ca
http://aep.alberta.ca

From: Biftu, Getu [mailto:Getu_Biftu@golder.com]
Sent: March 18, 2016 16:23
To: Shoma Tanzeeba
Subject: RE: Travel Times in the Red Deer River basin

Hi Shoma,
Sorry for the last minute request before your holiday. Here is the Table we had from Werner.

Flow (m^3/s)	Travel Time (hours)						
	Dickson Dam to confluence with Little Red Deer River	Little Red Deer River to the City of Red Deer	City of Red Deer to confluence with Blindman River	Blindman River confluence to Nevis	Nevis to Big Valley	Big Valley to Drumheller	Drumheller to confluence with Rosebud River
0.00(1)	22.87	134.92	83.31	262.86	254.46	216.36	36.17
0.50	11.68	68.93	45.11	142.32	137.78	117.15	19.58
1	8.75	51.62	34.63	109.28	105.79	89.94	15.04
3	5.53	32.63	22.78	71.89	69.59	59.17	9.89
6	4.14	24.44	17.49	55.19	53.43	45.43	7.59
10	3.35	19.75	14.40	45.43	43.98	37.39	6.25
30	2.12	12.48	9.47	29.88	28.93	24.60	4.11
60	1.58	9.35	7.27	22.95	22.21	18.89	3.16
100	1.58	9.32	5.99	18.89	18.28	15.54	2.60
300	1.55	9.16	3.94	12.42	12.03	10.23	1.71
600	1.52	8.94	3.02	9.54	9.23	7.85	1.31

Flow (m^3/s)	Travel Time (hours)						
	Dickson Dam to confluence with Little Red Deer River	Little Red Deer River to the City of Red Deer	City of Red Deer to confluence with Blindman River	Blindman River confluence to Nevis	Nevis to Big Valley	Big Valley to Drumheller	Drumheller to confluence with Rosebud River
1,000	1.47	8.66	2.49	7.85	7.60	6.46	1.08
3,000	1.27	7.48	2.30	7.27	7.04	5.98	1.00
6,000	1.05	6.21	2.07	6.54	6.34	5.39	0.90
10,000	0.86	5.07	1.83	5.78	5.59	4.75	0.79
20,000	0.59	3.47	1.42	4.46	4.32	3.68	0.61
30,000	0.45	2.64	1.15	3.64	3.52	3.00	0.50

Thank you so much for your help and have a nice break.

Best regards,

Getu

Getu Biftu (Ph.D., P.Eng.) | Principal, Sr. Water Resources Engineer | **Golder Associates Ltd.**
102, 2535 - 3rd Avenue S.E., Calgary, Alberta, Canada T2A 7W5
T: +1 (403) 299 5600 | **D:** +1 403 260 2236 | **F:** +1 (403) 299 5606 | **C:** +1 403 473 8576 | **E:** Getu_Biftu@golder.com | **www.golder.com**

Work Safe, Home Safe

-----Original Message-----
From: Werner Herrera [mailto:Werner.Herrera@aer.ca]
Sent: Friday, March 18, 2016 10:59 AM
To: Nesa Ilich <nilich@optimal-solutions-ltd.com>
Cc: Biftu, Getu <Getu_Biftu@golder.com>; Muhammed.Sabur@gov.ab.ca; shoma.tanzeeba@gov.ab.ca
Subject: RE: Travel Times in the Red Deer River basin

Good morning Nesa,

Nice to hear from you, now to answer your question the travel time tables provided came directly from the historical naturalizing flow Hydstra model. For all intent and purposes at the time of the work I also checked with Colleen Walford to make sure that I was using an up to date table. There might be difference in tables because it is possible the model configurations are different with different reaches of interest in each model. The contact person on this will be Mohammed Sabur in the Lethbridge office, and Shoma Tanzeeba in Calgary, either of them have access to the routing tables straight from the Hydstra model.

I hope this answers your question and if you have any other questions please let me know.

Sincerely;

Werner Herrera, M.Eng., P.Eng.
Hydrologist, Oil and Gas Authorizations
Alberta Energy Regulator
e werner.herrera@aer.ca tel 587-982-2462 inquiries 1-855-297-8311 24-hour emergency 1-800-222-6514
www.aer.ca

-----Original Message-----
From: Nesa Ilich [mailto:nilich@optimal-solutions-ltd.com]
Sent: Thursday, March 17, 2016 2:31 PM
To: Werner Herrera
Cc: Biftu, Getu
Subject: Fwd: Travel Times in the Red Deer River basin

Hi Werner,

Getu and I have been working together on a flood assessment study in the Red Deer River fro AEP. As part of this study, we had to assess daily natural flows up to 2015. This was done based on the RBAT setup that you and I tested together in 2009 when RBAT was still under development as part of the PPWB contract. I re-used the same travel time tables that I got from you for the entire river basin at that time, and I think those were downloaded from Hydrol database. Alberta River Forecasting division is asking where those travel time tables could be located within the AEP database? Can you help us with this by providing some clues as to where this information could be found, or by referring this issue to a hydrologist within AEP who took over your previous duties?

Your help would be sincerely appreciated. Our client on AEP side is Khaled Akhtar (Khaled.Akhtar@gove.ab.ca, 780 644 2689). He is new to AEP and he will use all the help he can get to locate these files. Your timely response to this would be sincerely appreciated.

Regards, Nesa

_____

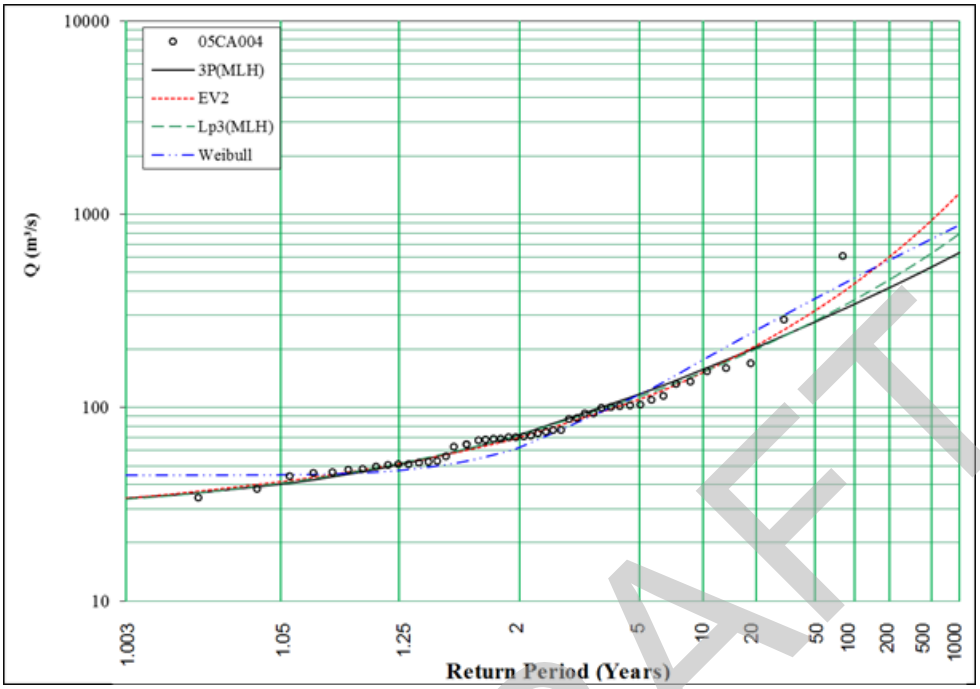
APPENDIX C

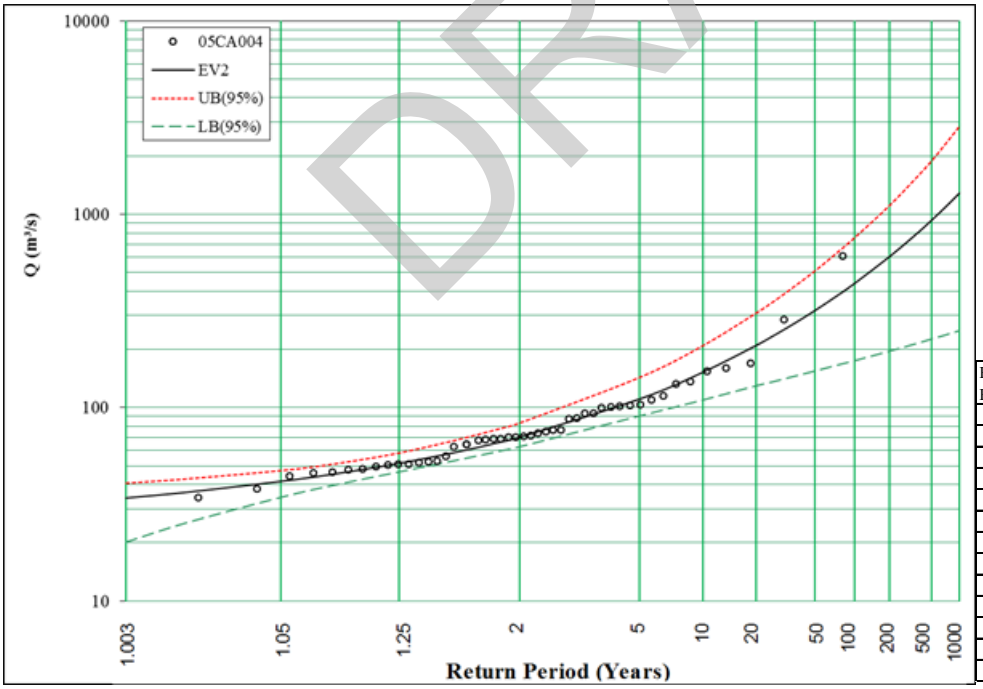
Frequency Analysis – Graphs and Tables

C1.0 RESULTS FLOOD FREQUENCY ANALYSIS – RECORDED AND NATURALIZED

Red Deer River Reaches

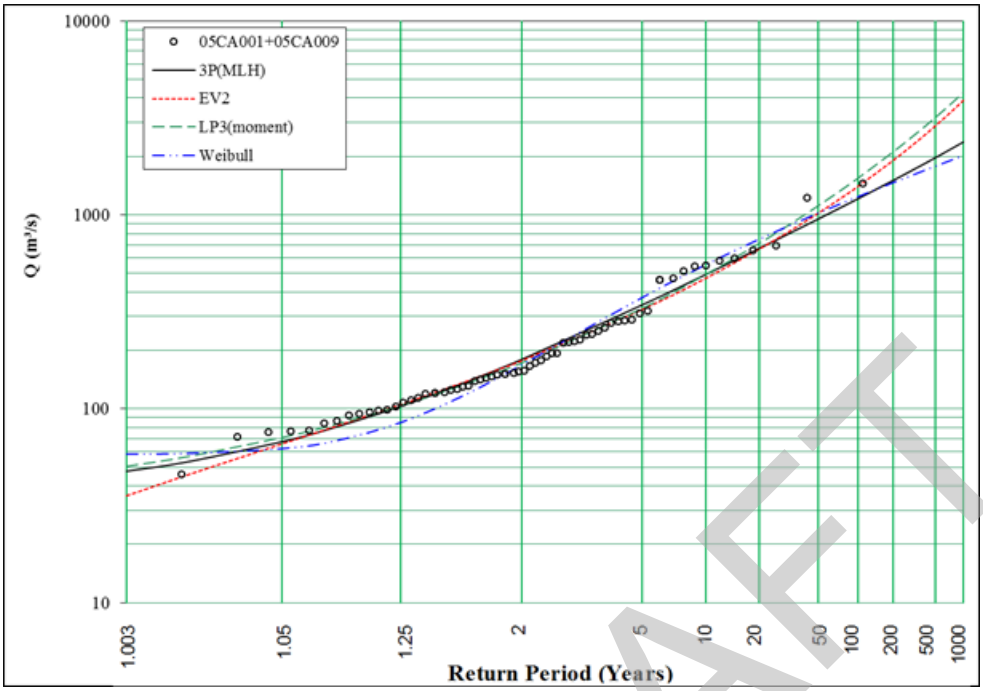
Red Deer River above Panther River (WSC Station No. 05CA004) – Node 500

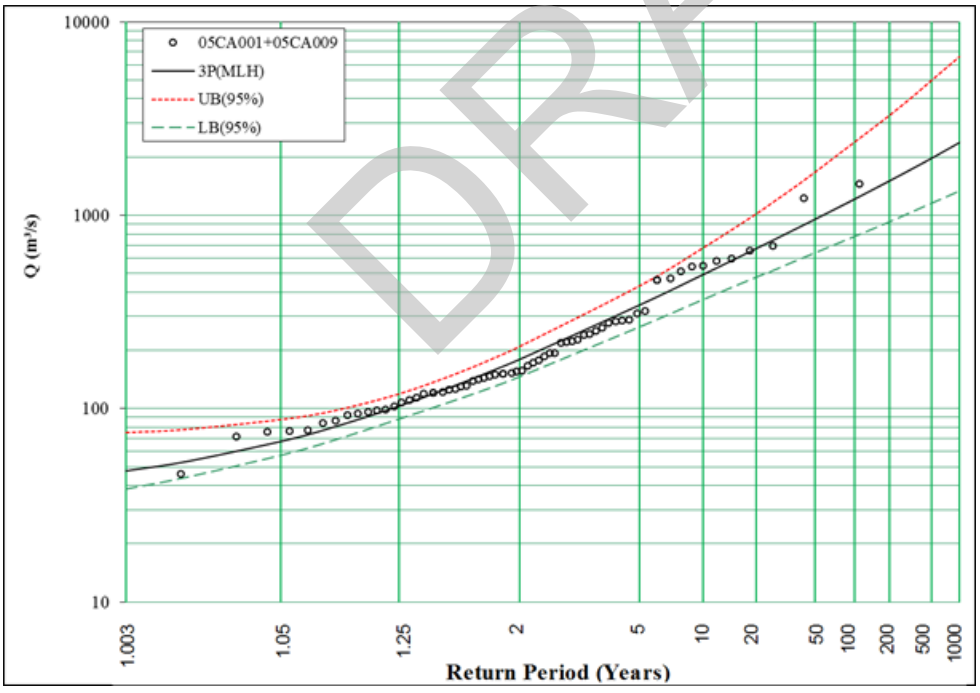




Return Period	3P	EV	LP3	Weibull
2	72	70	72	62
5	117	111	114	117
10	158	153	153	177
20	204	209	200	250
35	247	270	247	319
50	278	318	281	366
75	315	384	325	424
100	343	438	360	468
200	418	605	459	580
350	486	785	556	678
500	533	928	628	744
750	590	1122	720	822
1000	633	1285	793	880

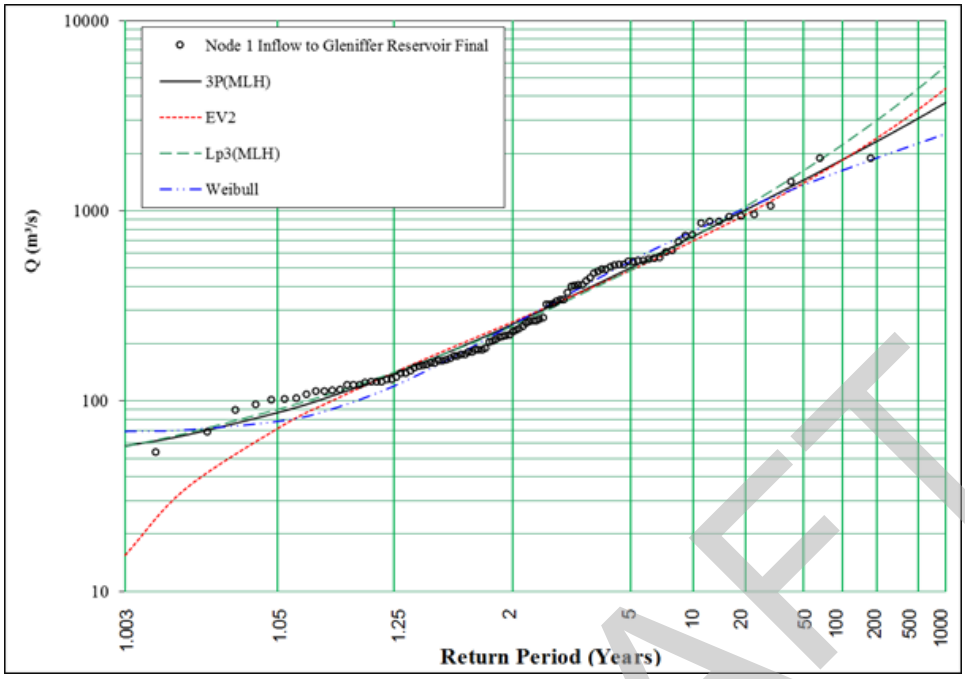
Red Deer River below Timber Creek (WSC Station No. 05CA001) – Node 501

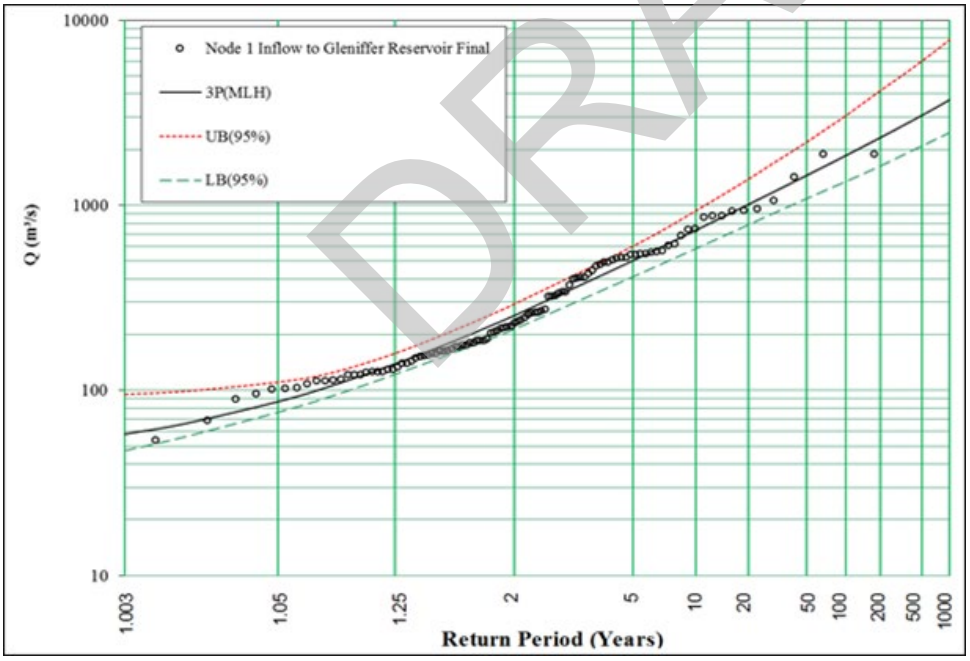




Return Period	3P	EV	LP3	Weibull
2	180	177	173	168
5	343	325	331	374
10	493	471	494	553
20	671	663	711	746
35	837	865	940	910
50	954	1020	1116	1019
75	1099	1228	1351	1145
100	1210	1399	1543	1237
200	1507	1908	2112	1463
350	1778	2445	2705	1651
500	1968	2862	3160	1774
750	2199	3420	3765	1915
1000	2375	3879	4258	2017

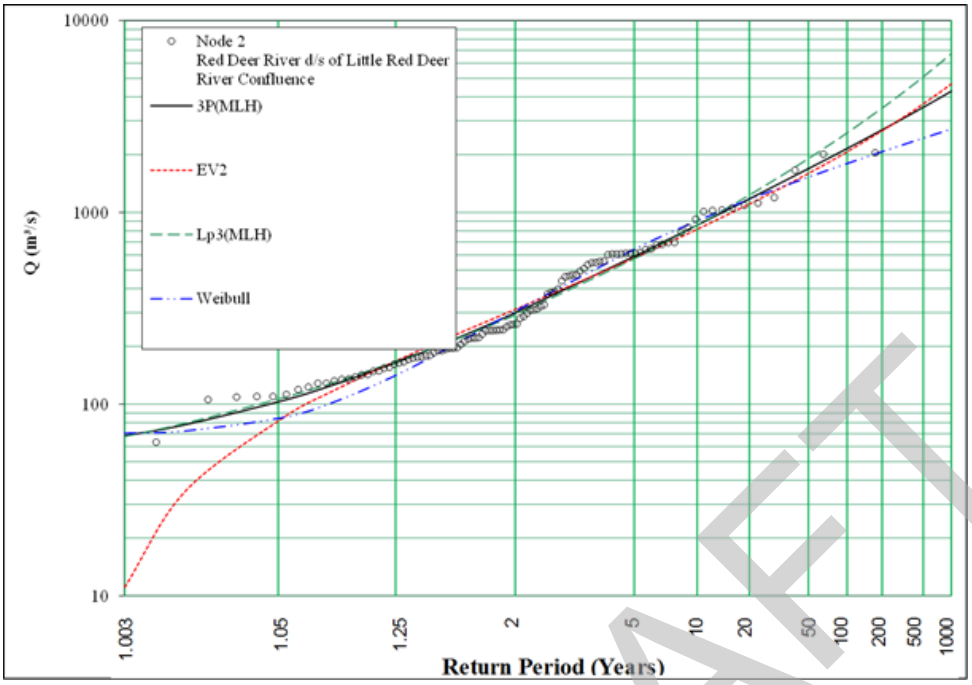
Red Deer River above Gleniffer Reservoir – Node 107

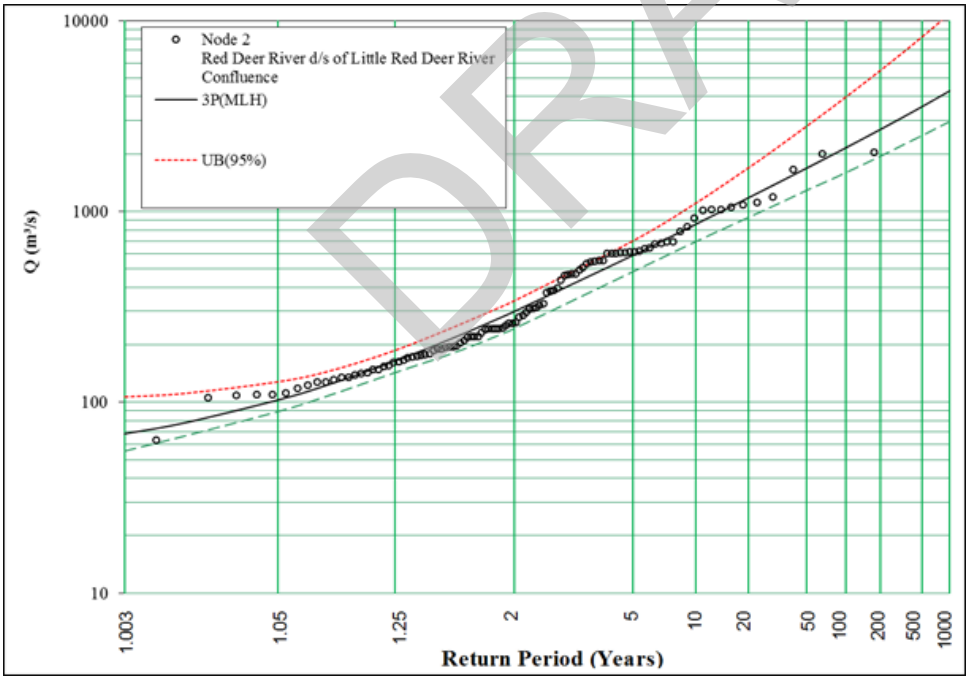




Return Period	3P	EV	LP3	Weibull
2	254	262	247	252
5	503	490	488	544
10	733	699	732	781
20	1009	958	1051	1028
35	1268	1215	1381	1233
50	1451	1407	1631	1365
75	1679	1655	1960	1518
100	1854	1853	2227	1628
200	2323	2421	3002	1896
350	2754	2990	3792	2115
500	3055	3416	4388	2256
750	3425	3968	5168	2418
1000	3706	4410	5796	2534

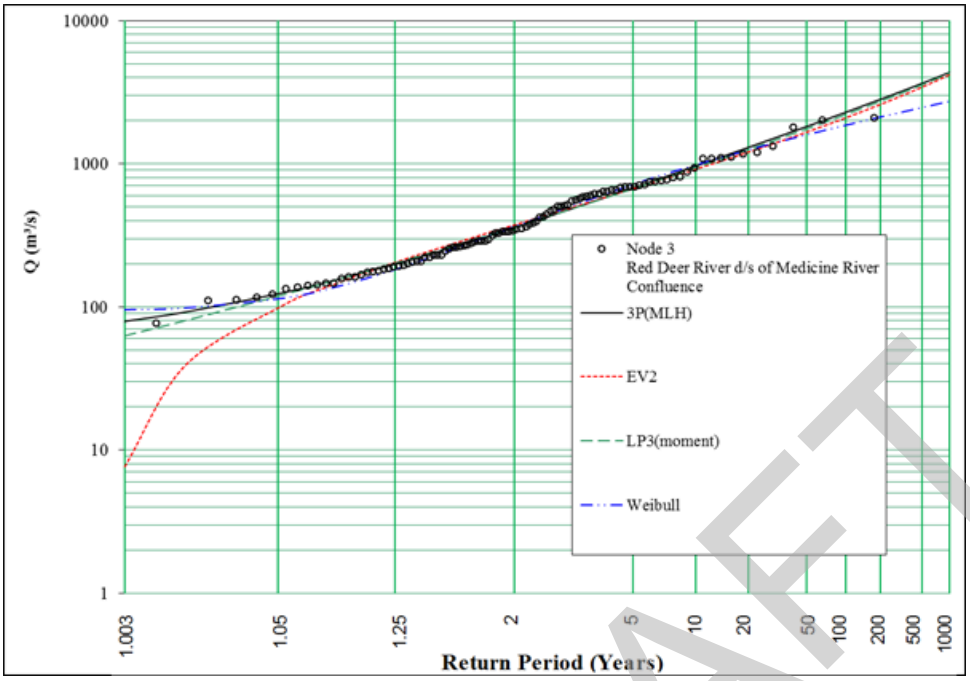
Red Deer River downstream of Little Red Deer River Confluence – Node 109

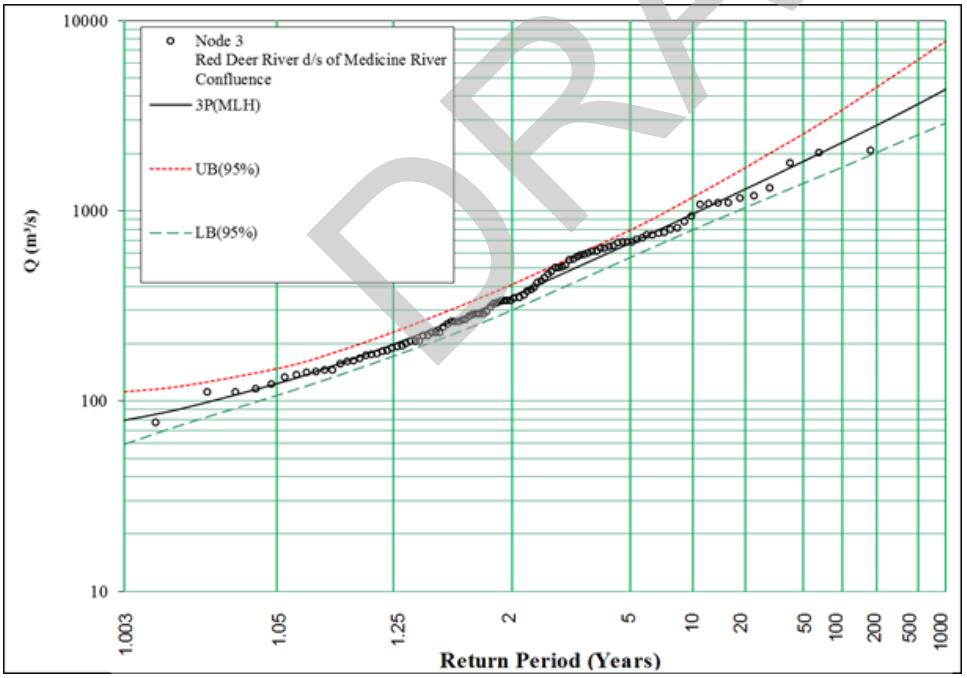




Return Period	3P	EV	LP3	Weibull
2	299	312	291	305
5	590	579	573	641
10	858	817	859	903
20	1177	1107	1232	1169
35	1477	1389	1615	1386
50	1689	1597	1906	1525
75	1952	1862	2288	1685
100	2154	2073	2598	1798
200	2693	2666	3495	2073
350	3189	3252	4409	2296
500	3535	3683	5098	2439
750	3960	4238	5998	2602
1000	4281	4677	6722	2718

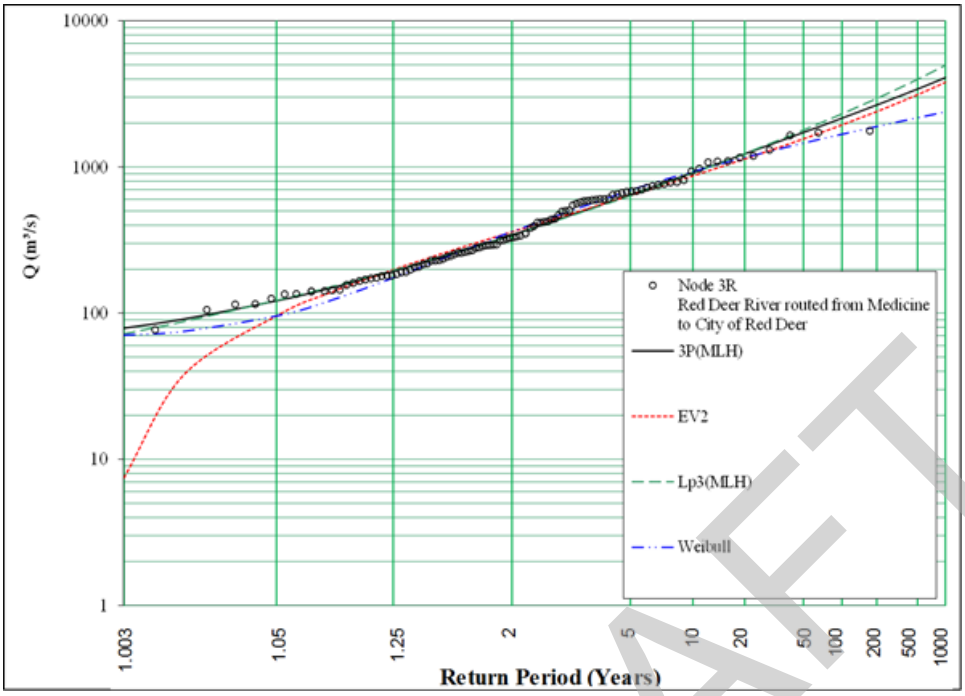
Red Deer River downstream of Medicine River Confluence – Node 110

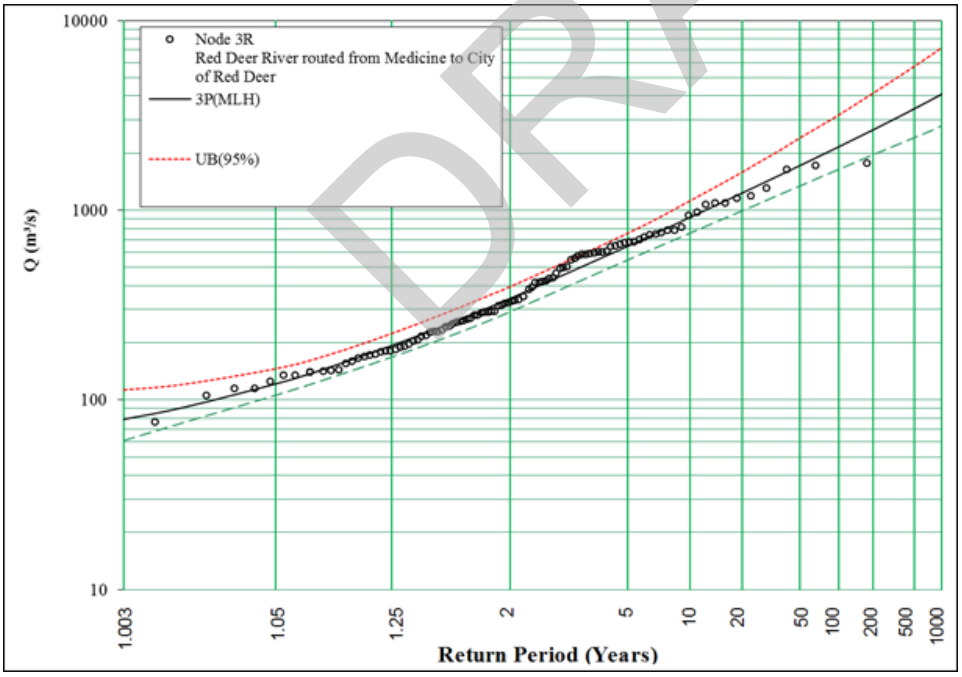




Return Period	3P	EV	LP3	Weibull
2	356	374	362	364
5	678	668	671	718
10	965	916	943	984
20	1299	1203	1259	1249
35	1606	1471	1552	1462
50	1822	1662	1760	1598
75	2086	1902	2016	1753
100	2288	2087	2213	1862
200	2820	2593	2740	2126
350	3304	3072	3226	2339
500	3639	3415	3568	2474
750	4046	3845	3989	2628
1000	4353	4179	4309	2737

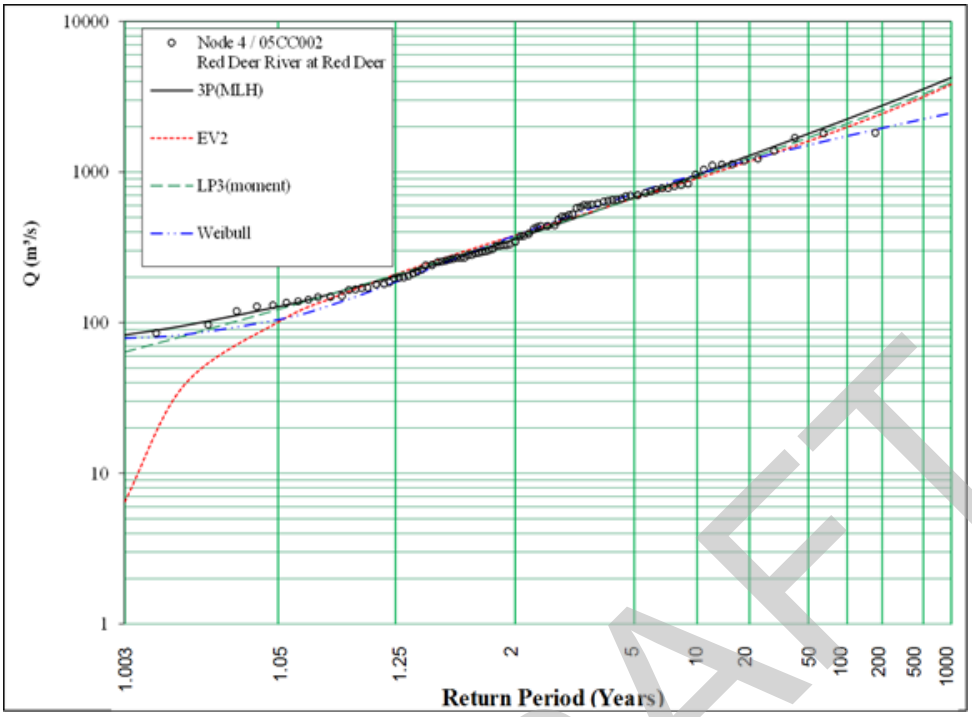
Red Deer River upstream of Red Deer – Node 111

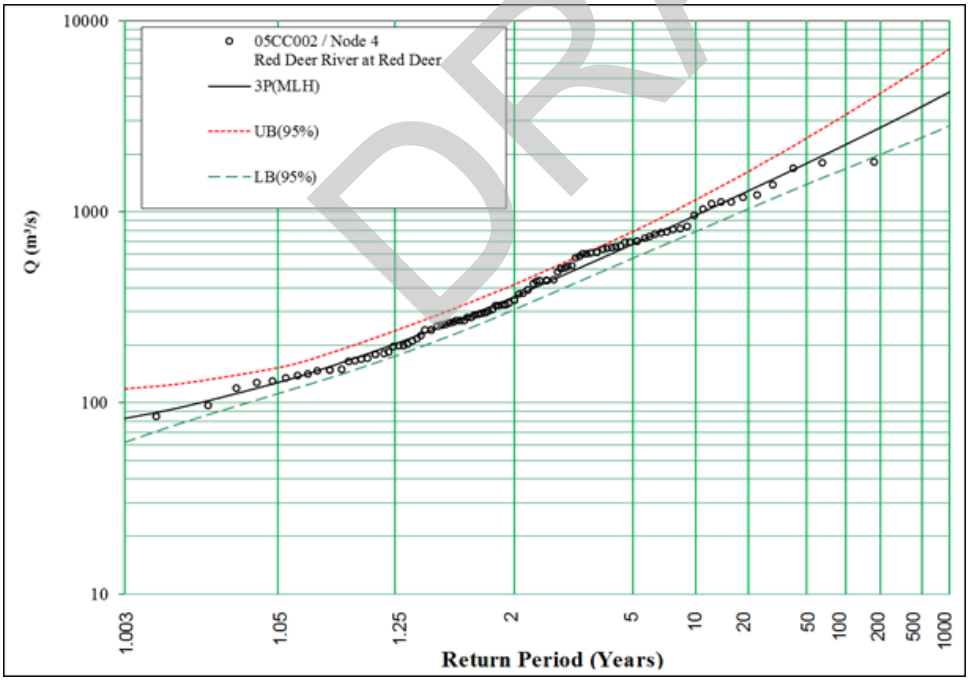




Return Period	3P	EV	LP3	Weibull
2	342	361	341	361
5	647	639	635	693
10	917	870	907	930
20	1231	1136	1238	1160
35	1520	1383	1556	1342
50	1723	1558	1788	1456
75	1971	1776	2080	1584
100	2159	1943	2309	1675
200	2658	2399	2942	1891
350	3110	2827	3549	2063
500	3422	3132	3986	2172
750	3803	3512	4537	2295
1000	4089	3806	4966	2382

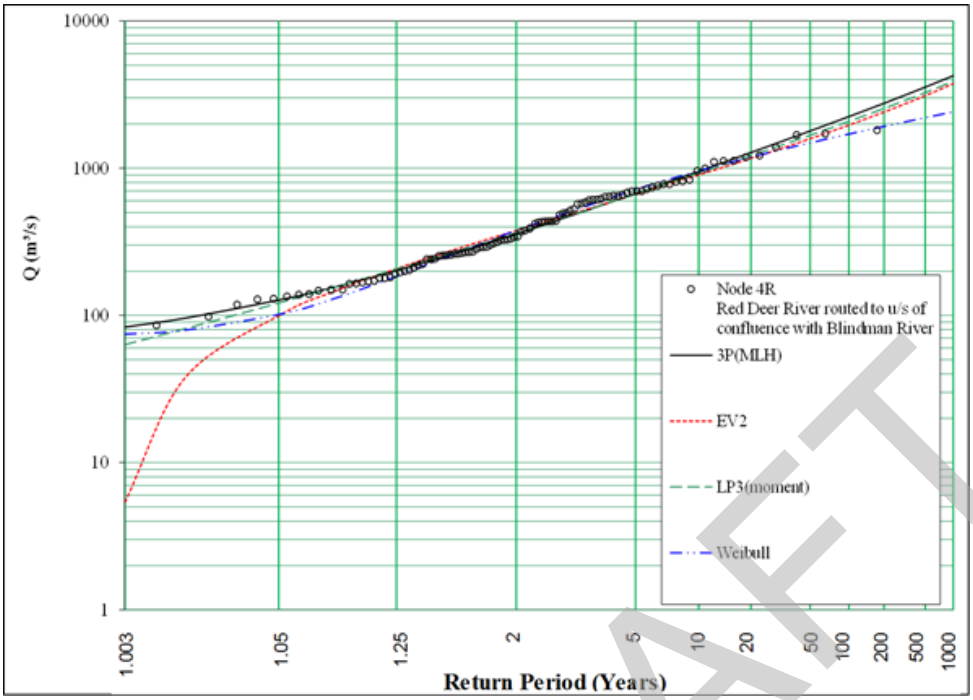
Red Deer River at Red Deer (05CC002) – Node 202

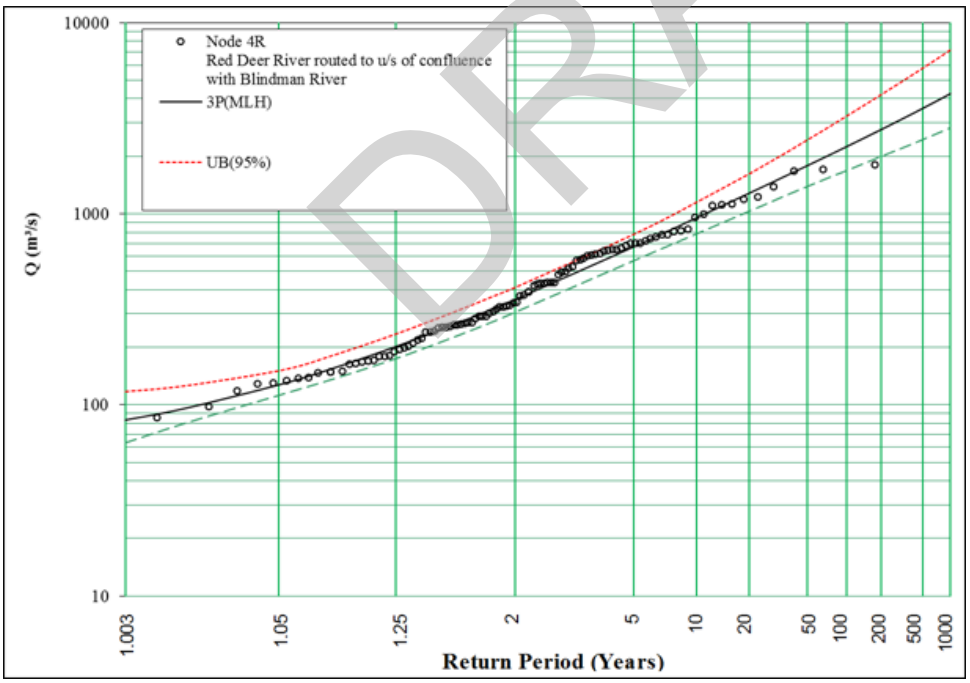




Return Period	3P	EV	LP3	Weibull
2	359	380	368	379
5	677	669	672	721
10	959	907	932	965
20	1285	1178	1230	1202
35	1585	1427	1502	1389
50	1794	1603	1692	1507
75	2051	1821	1926	1640
100	2246	1988	2103	1733
200	2761	2440	2573	1955
350	3228	2861	3001	2132
500	3551	3160	3299	2244
750	3943	3530	3663	2371
1000	4238	3815	3938	2460

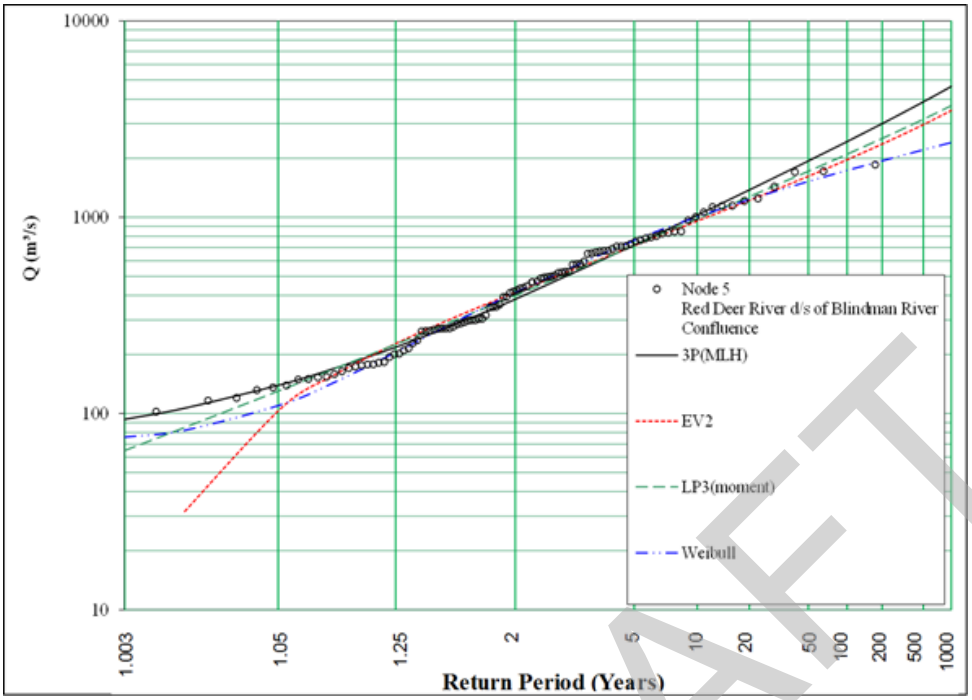
Red Deer River below Waskasoo and above Blindman River – Node 112/113

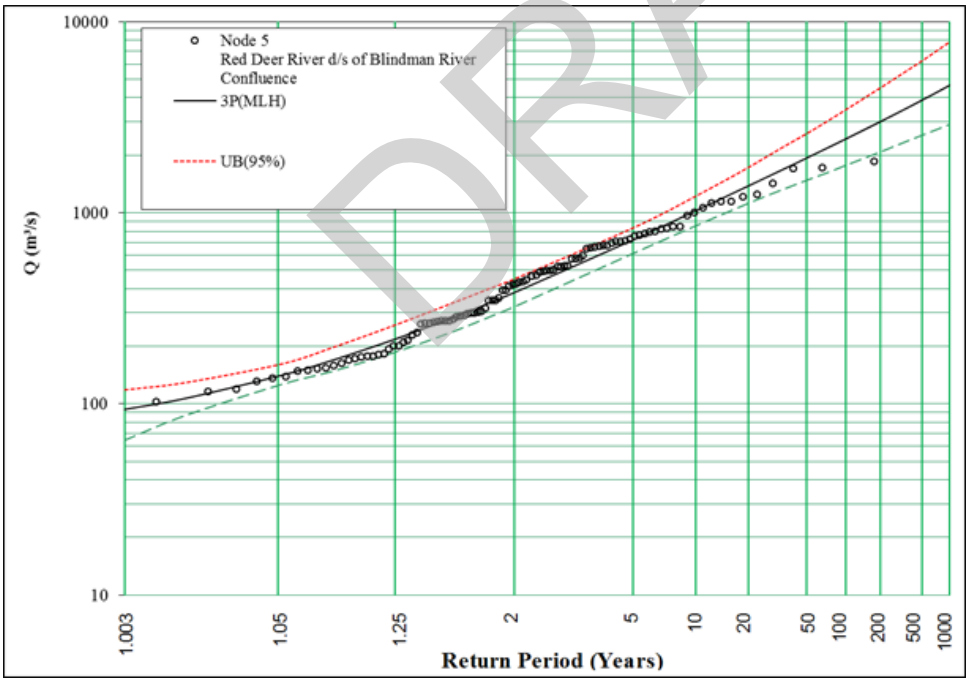




Return Period	3P	EV	LP3	Weibull
2	356	378	366	378
5	672	664	667	716
10	953	900	925	957
20	1279	1168	1220	1189
35	1579	1414	1490	1372
50	1790	1587	1679	1487
75	2047	1802	1910	1616
100	2243	1967	2086	1707
200	2761	2410	2552	1923
350	3231	2824	2976	2095
500	3557	3116	3271	2204
750	3952	3479	3631	2327
1000	4250	3758	3904	2413

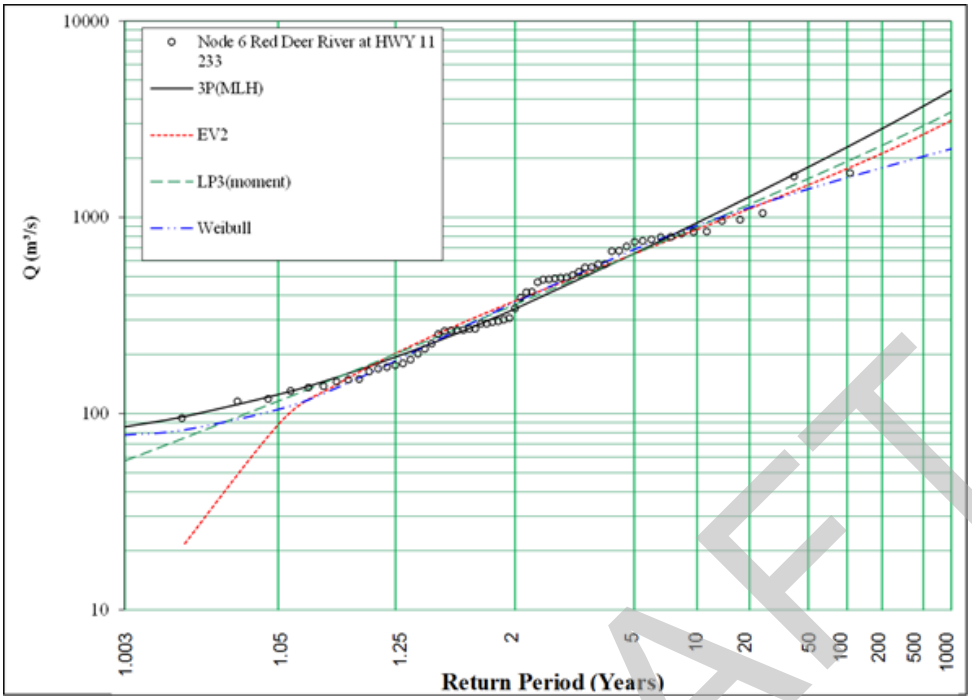
Red Deer River below Blindman River Confluence – Node 114

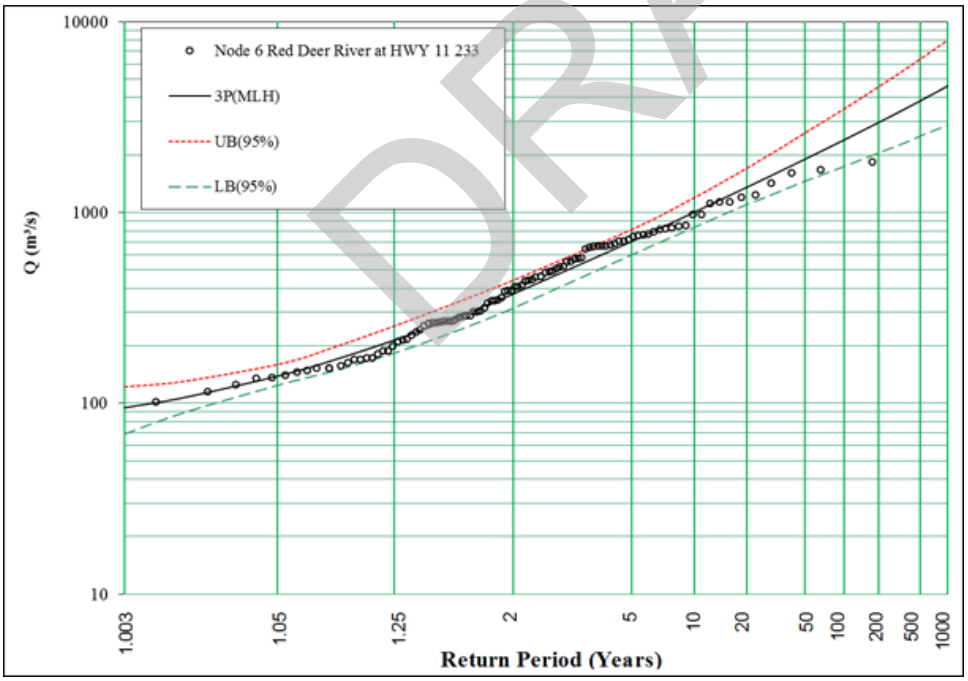




Return Period	3P	EV	LP3	Weibull
2	382	414	399	414
5	722	717	718	763
10	1026	957	982	1003
20	1380	1220	1275	1232
35	1707	1456	1537	1410
50	1937	1618	1717	1521
75	2218	1816	1934	1645
100	2433	1966	2097	1732
200	3002	2361	2523	1938
350	3519	2719	2901	2102
500	3877	2967	3161	2204
750	4313	3270	3473	2320
1000	4642	3500	3707	2401

Red Deer River at Highway 11 – Node 115

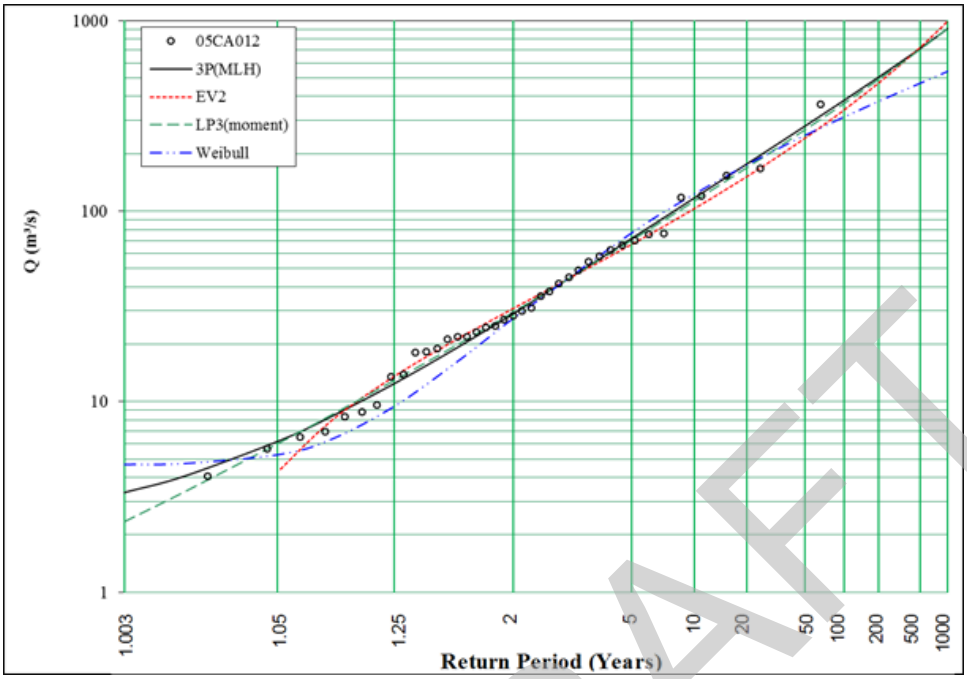


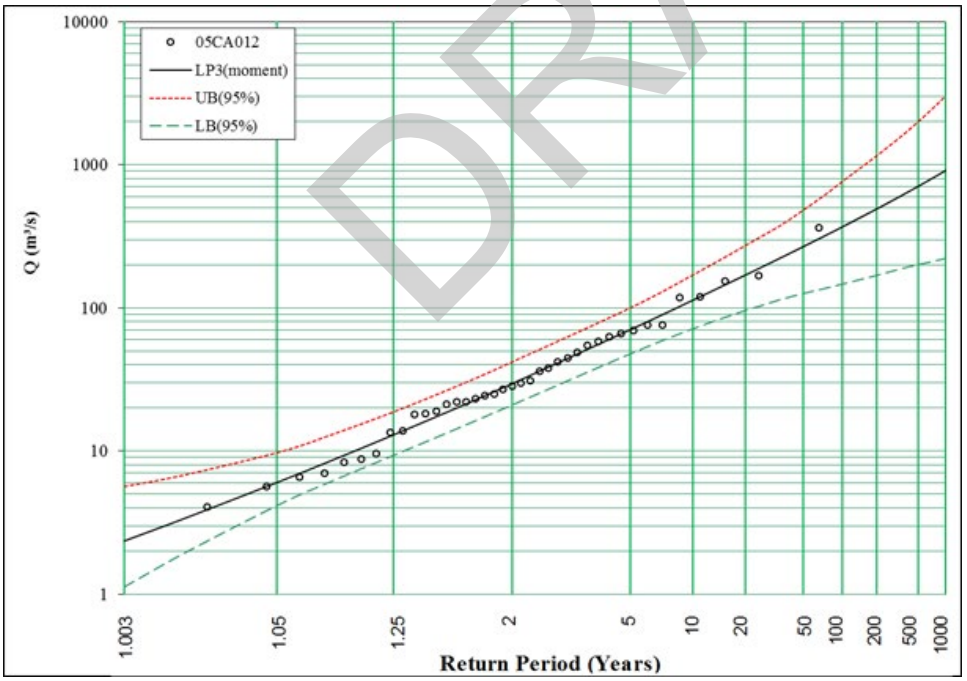


Return Period	3P	EV	LP3	Weibull
2	374	405	391	406
5	706	701	702	747
10	1004	936	960	983
20	1353	1195	1249	1207
35	1677	1428	1509	1382
50	1904	1589	1687	1491
75	2183	1785	1904	1613
100	2396	1933	2066	1699
200	2962	2326	2492	1901
350	3476	2682	2873	2062
500	3834	2930	3135	2163
750	4269	3234	3451	2276
1000	4598	3463	3688	2356

RED DEER RIVER TRIBUTARIES

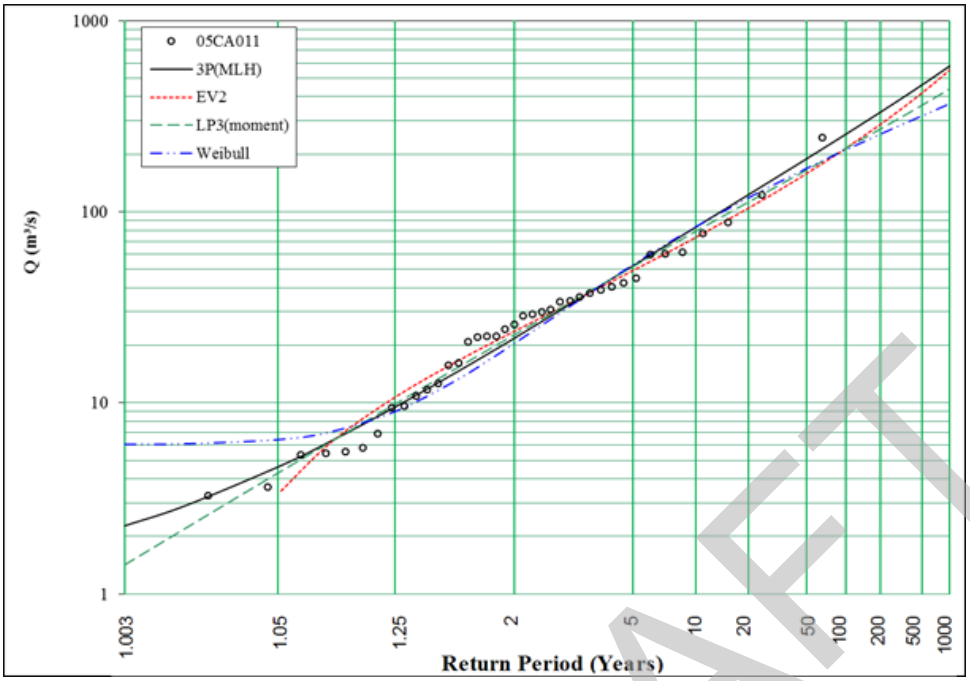
Fallentimber Creek near Sundre (05CA012) – Node 301

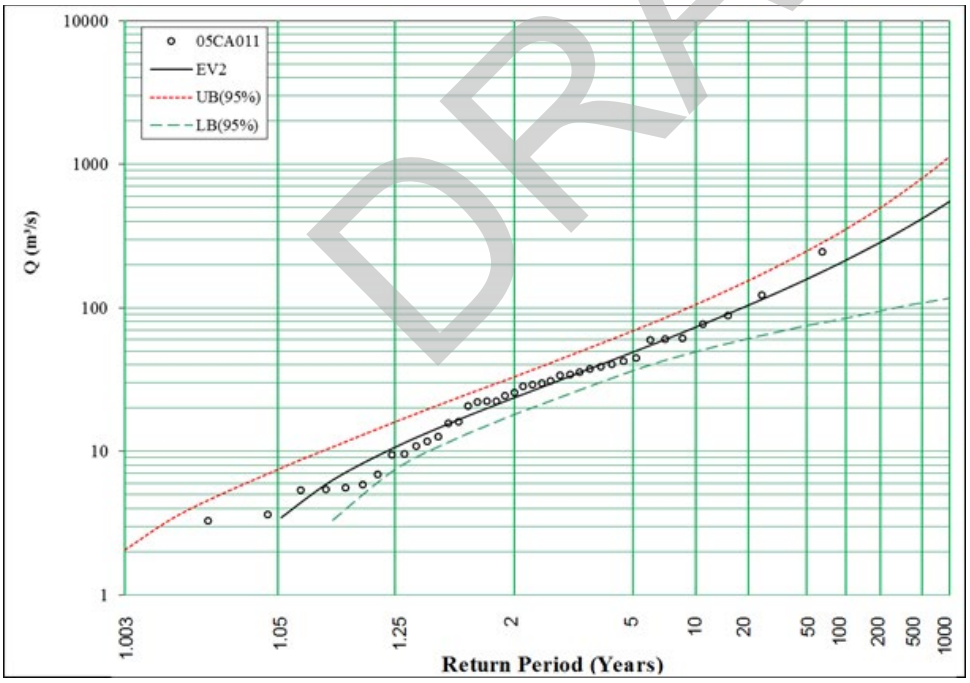




Return Period	3P	EV	LP3	Weibull
2	29	31	30	27
5	72	67	71	77
10	117	103	113	123
20	177	151	169	175
35	236	202	226	221
50	280	242	268	251
75	337	295	323	287
100	381	339	367	313
200	506	470	492	379
350	626	611	615	434
500	713	720	705	470
750	822	867	820	513
1000	907	989	911	543

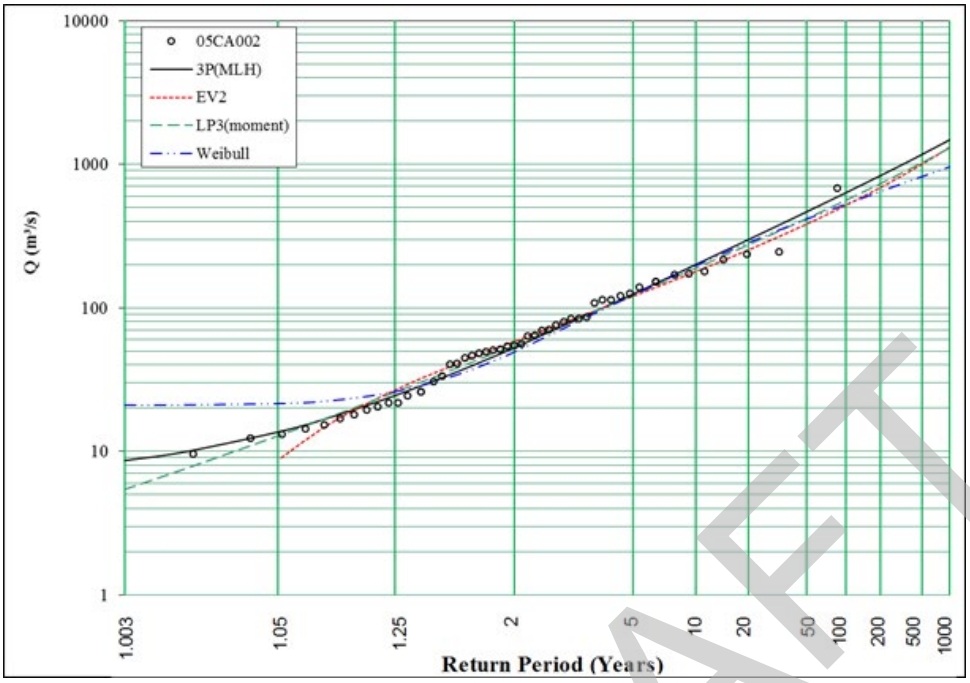
Bearberry Creek near Sundre (05CA011) – Node 302

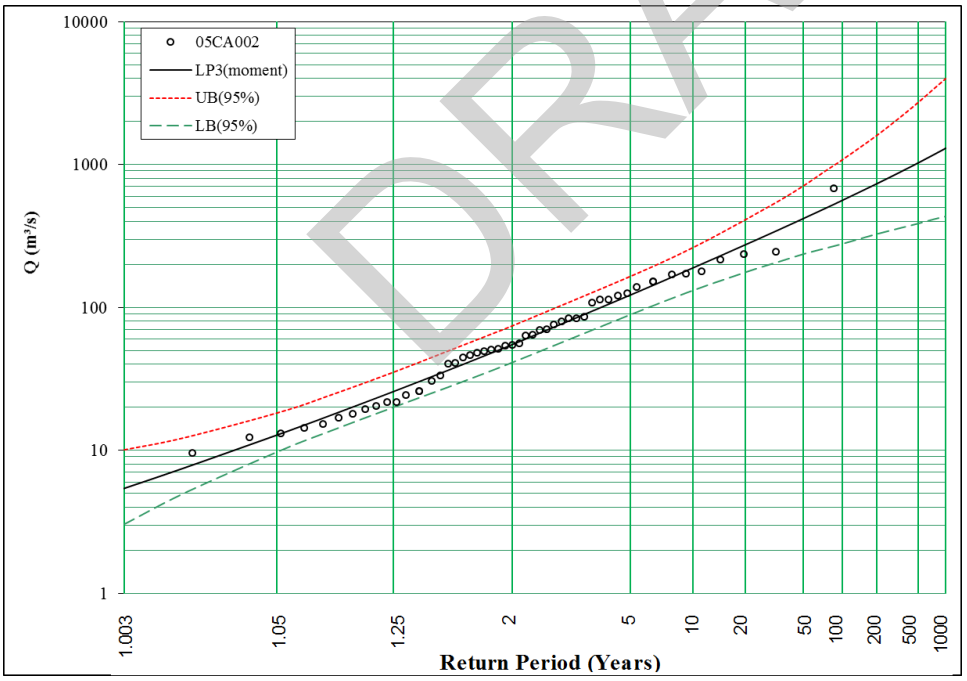




Return Period	3P	EV	LP3	Weibull
2	22	24	23	20
5	52	49	52	53
10	83	73	79	83
20	123	104	113	118
35	161	135	144	148
50	190	158	166	168
75	226	189	194	192
100	254	214	215	210
200	332	286	272	254
350	407	360	325	291
500	460	416	362	316
750	527	490	407	345
1000	578	550	441	366

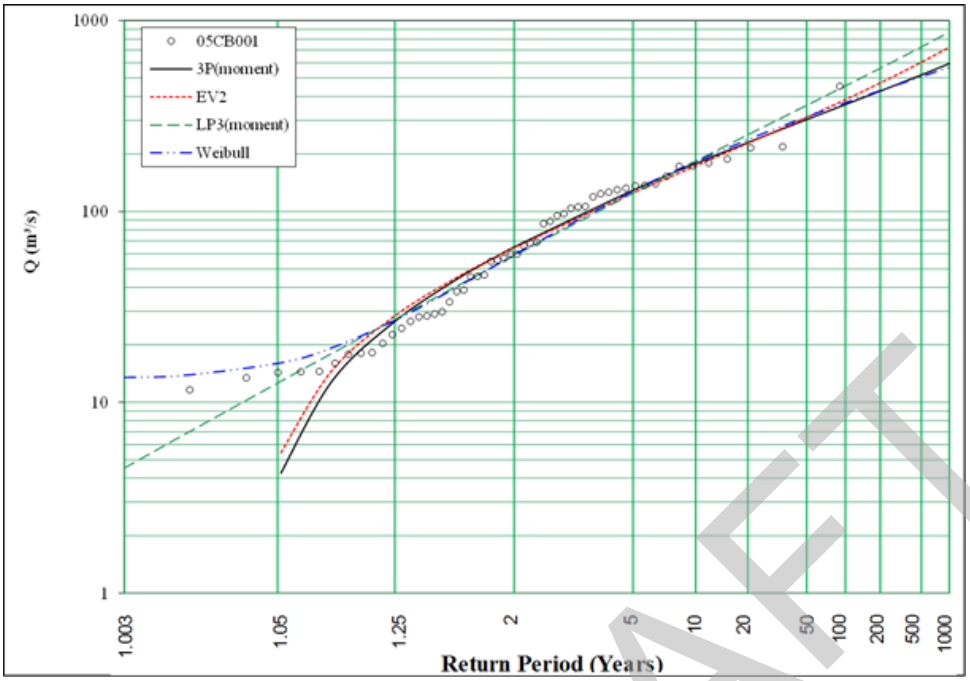
James River near Sundre (05CA002) – Node 303

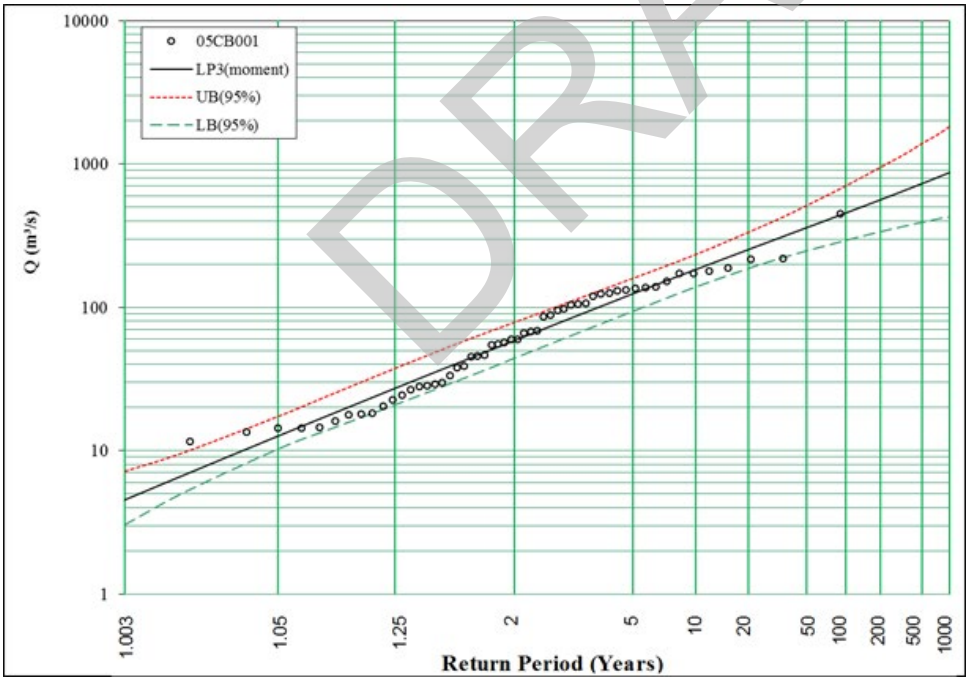




Return Period	3P	EV	LP3	Weibull
2	53	58	55	49
5	125	120	122	123
10	200	178	189	196
20	298	252	274	283
35	395	326	358	361
50	467	382	420	414
75	559	455	499	478
100	632	514	561	525
200	833	686	735	645
350	1027	861	903	748
500	1167	994	1025	816
750	1343	1168	1179	897
1000	1479	1309	1299	955

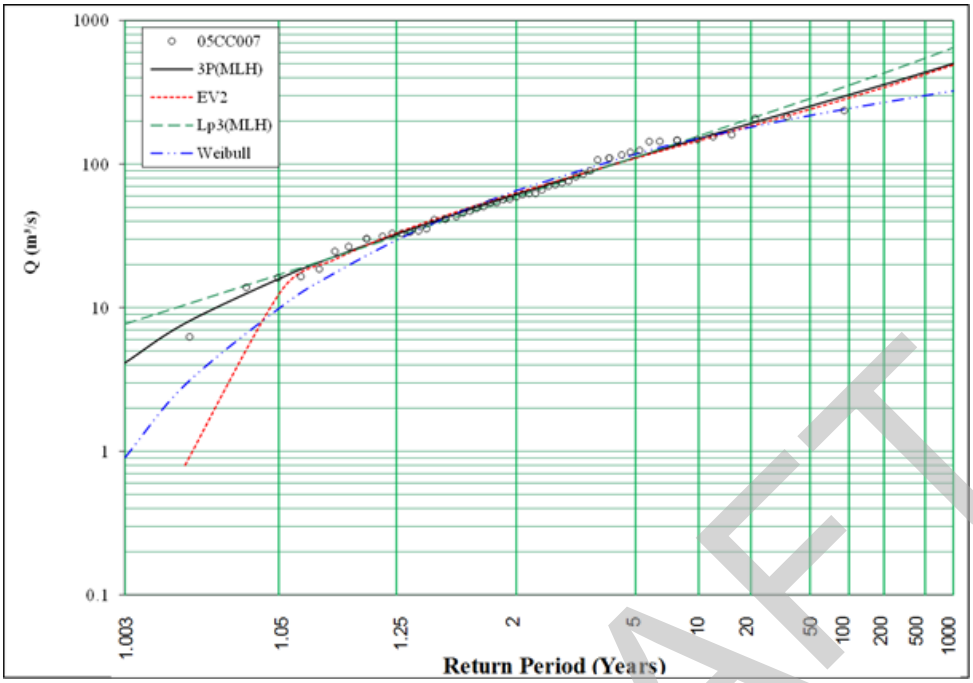
Little Red Deer River near the Mouth (05CB001) – Node 304

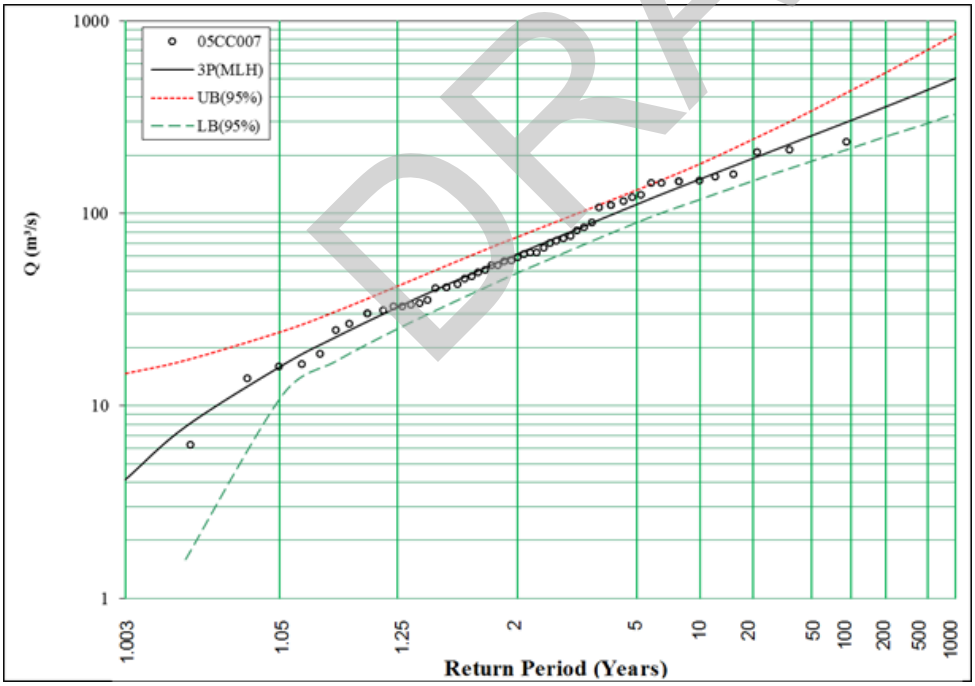




Return Period	3P	EV	LP3	Weibull
2	65	65	59	59
5	129	129	125	128
10	178	178	184	182
20	230	230	252	238
35	274	274	316	284
50	303	303	360	313
75	338	338	414	347
100	363	363	455	371
200	427	427	563	430
350	483	483	661	478
500	520	520	728	509
750	563	563	810	544
1000	595	595	871	569

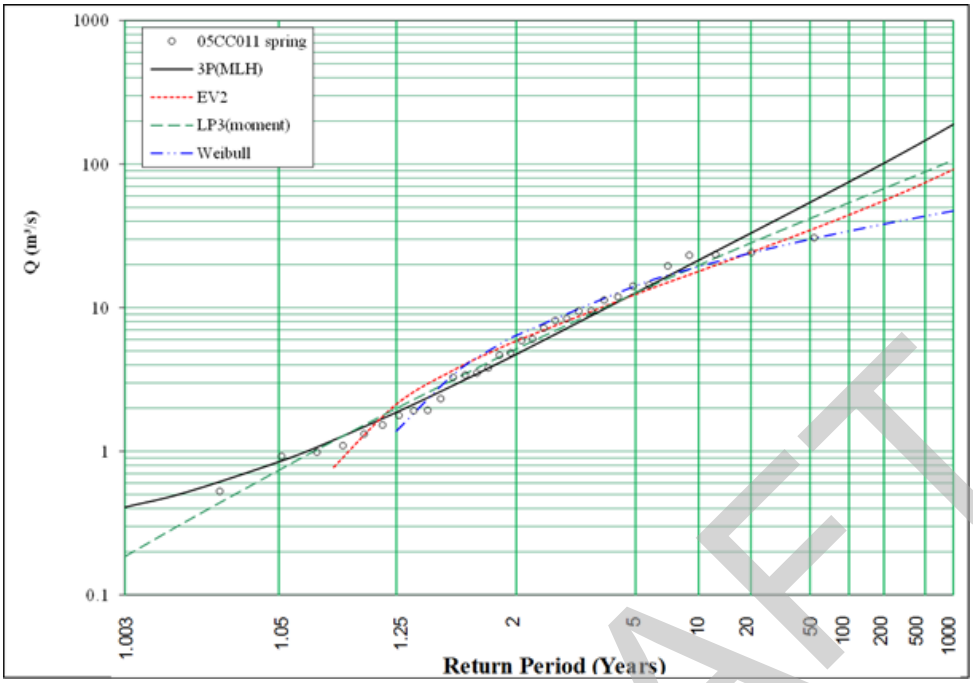
Medicine River near Eckville (05CC007) – Node 305

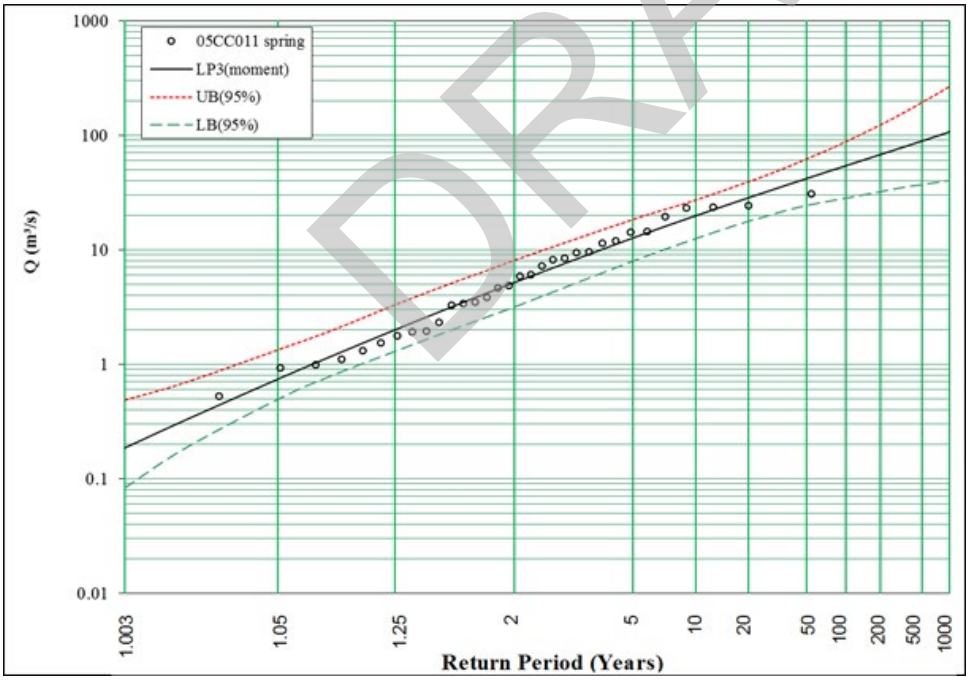




Return Period	3P	EV	LP3	Weibull
2	61	63	59	65
5	111	110	112	118
10	151	146	157	151
20	193	185	208	181
35	229	218	254	204
50	253	241	286	218
75	282	269	325	234
100	304	289	355	244
200	358	343	432	269
350	405	390	501	289
500	437	423	548	301
750	475	462	605	314
1000	503	491	648	324

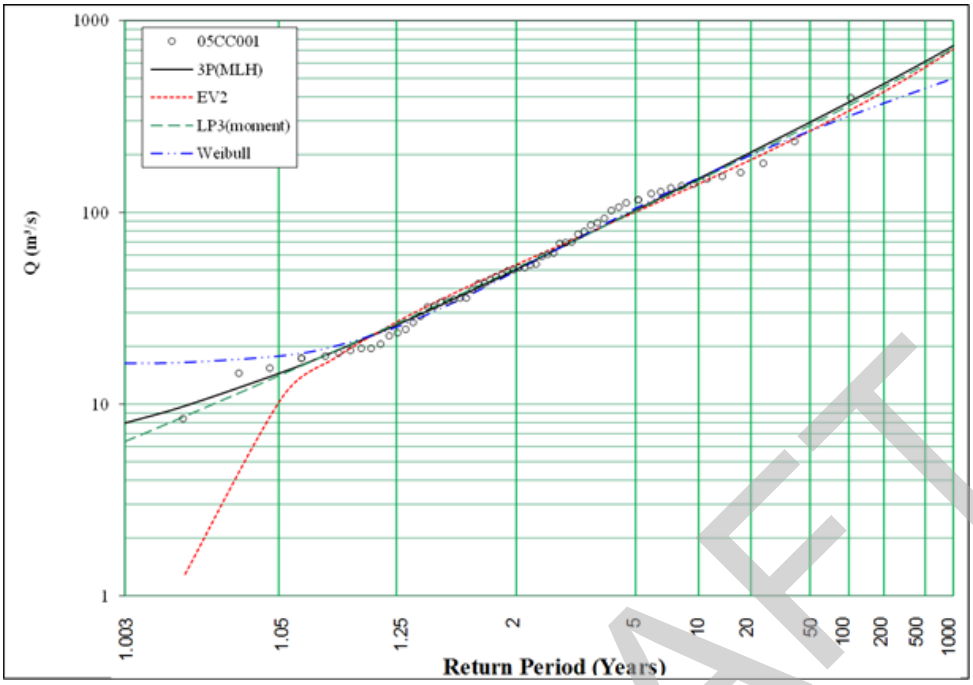
Waskasoo Creek at Red Deer (05CC011) – Node 307

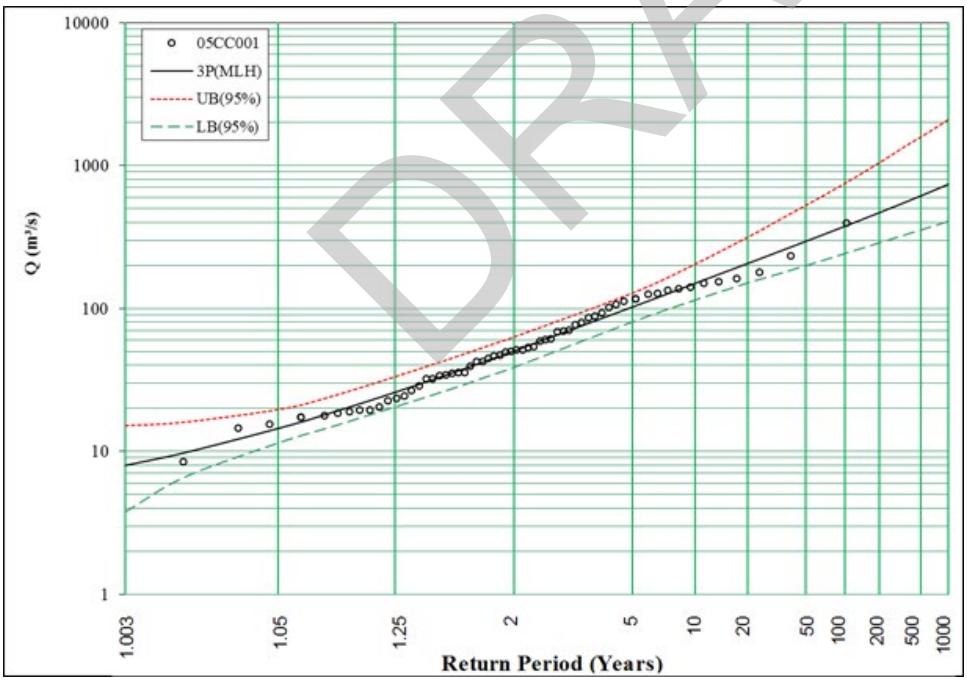




Return Period	3P	EV	LP3	Weibull
2	5	6	5	6
5	13	12	13	14
10	21	18	20	19
20	33	24	28	24
35	45	30	36	28
50	54	35	42	30
75	66	40	49	32
100	75	44	54	34
200	102	56	68	38
350	128	67	80	42
500	146	74	89	44
750	170	84	99	46
1000	189	92	107	47

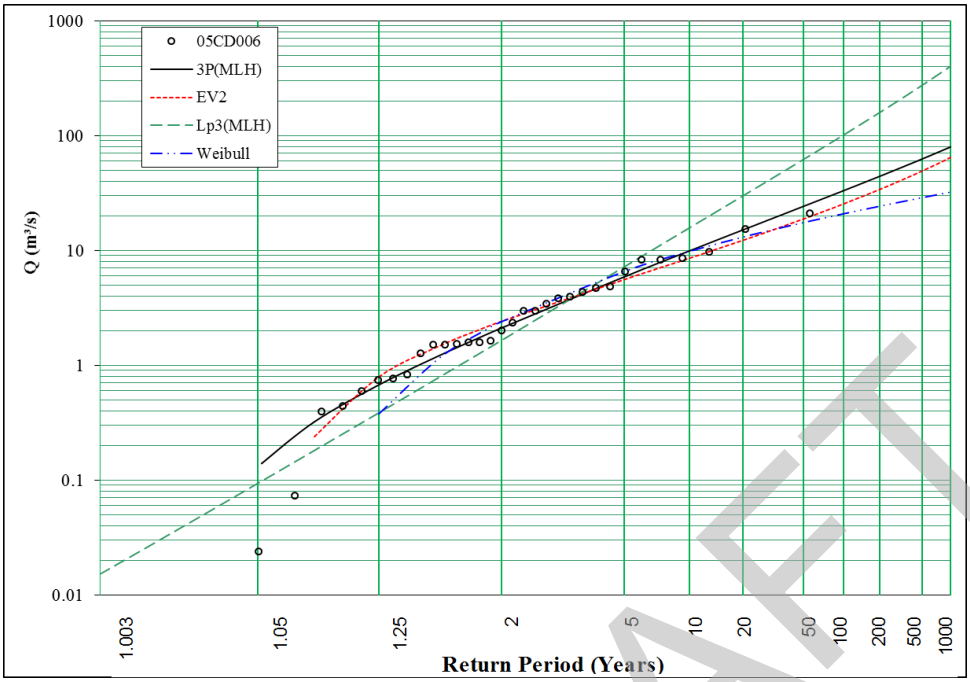
Blindman River near Blackfalds (05CC001) – Node 313

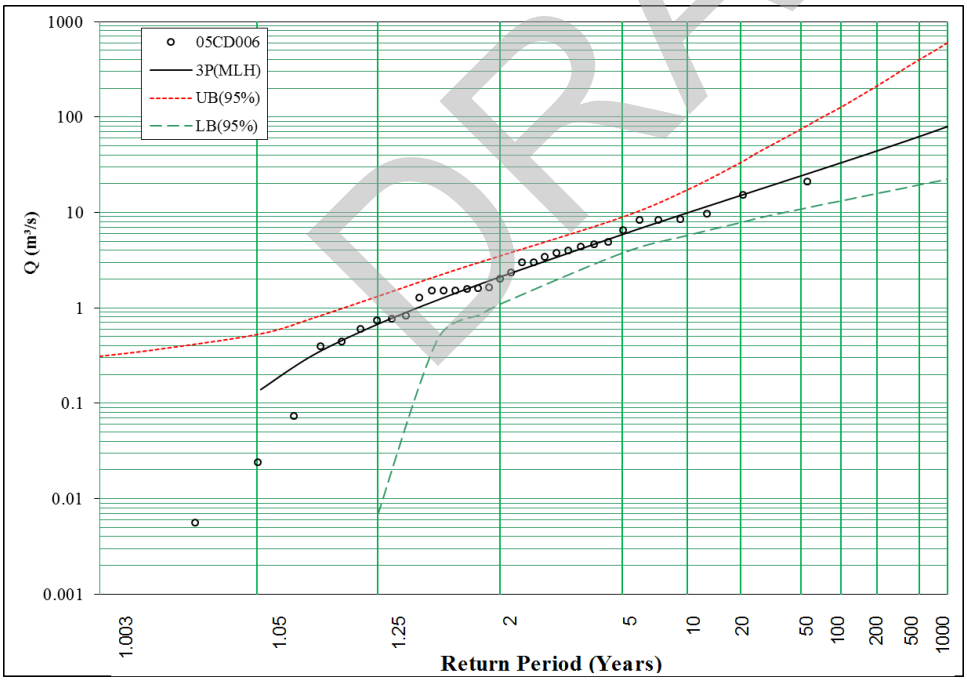




Return Period	3P	EV	LP3	Weibull
2	50	53	51	50
5	102	100	102	105
10	150	141	147	151
20	206	188	200	199
35	258	233	250	239
50	295	266	285	266
75	341	307	328	296
100	375	339	362	318
200	468	427	451	371
350	553	511	533	415
500	612	572	591	444
750	685	649	662	476
1000	739	709	716	500

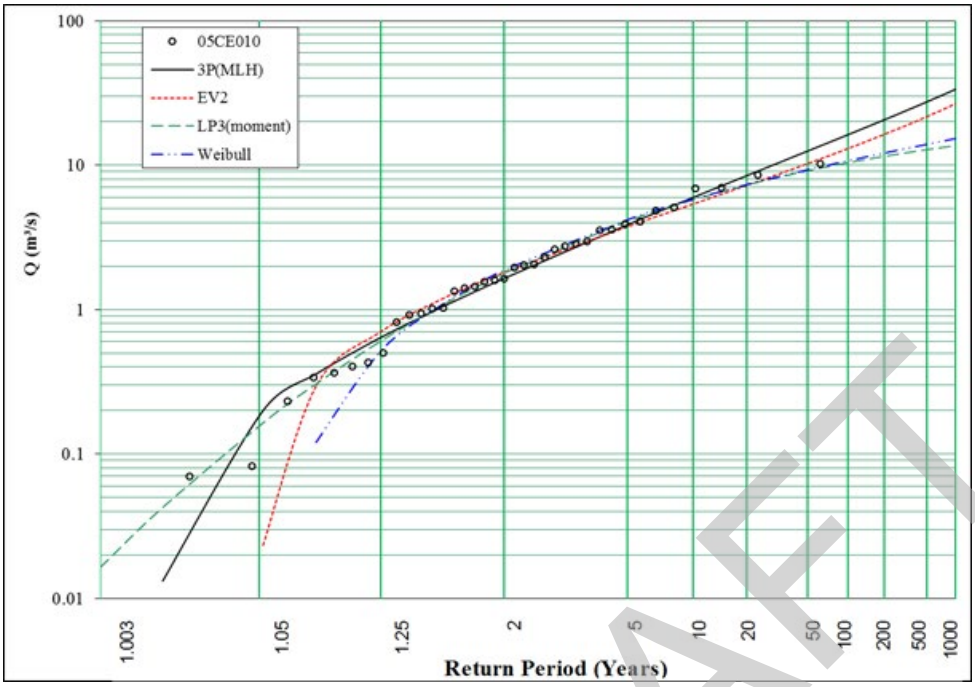
Haynes Creek near Haynes (05CD006)

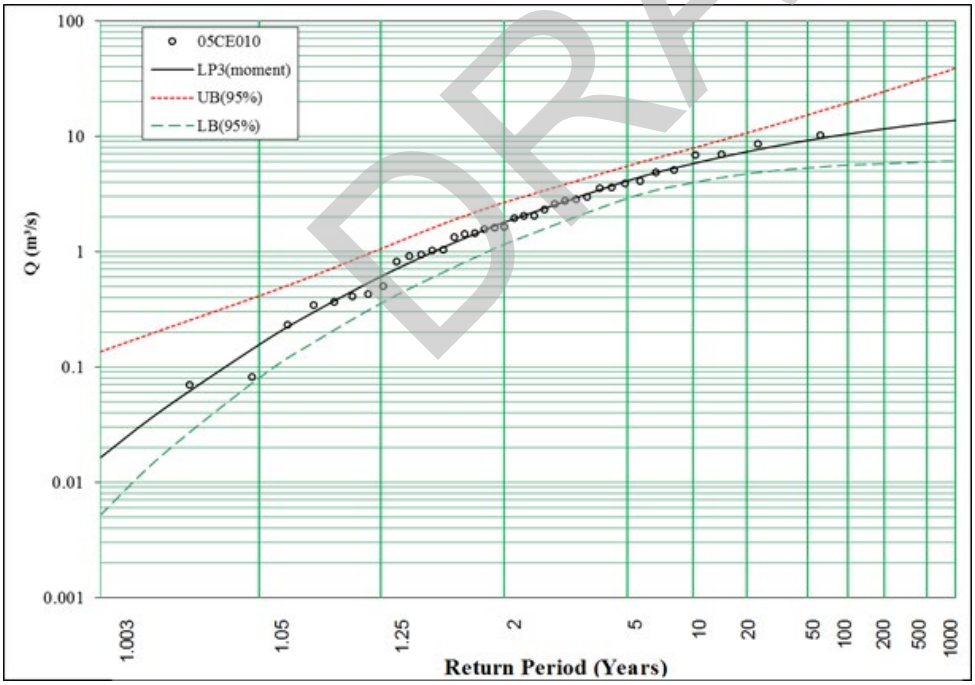




Return Period	3P	EV	LP3	Weibull
2	2	2	2	2
5	6	6	7	7
10	10	8	16	10
20	15	12	30	13
35	20	16	47	16
50	24	19	62	17
75	29	22	83	19
100	33	25	101	21
200	44	34	159	24
350	55	42	223	27
500	62	49	274	29
750	72	57	345	31
1000	80	64	403	32

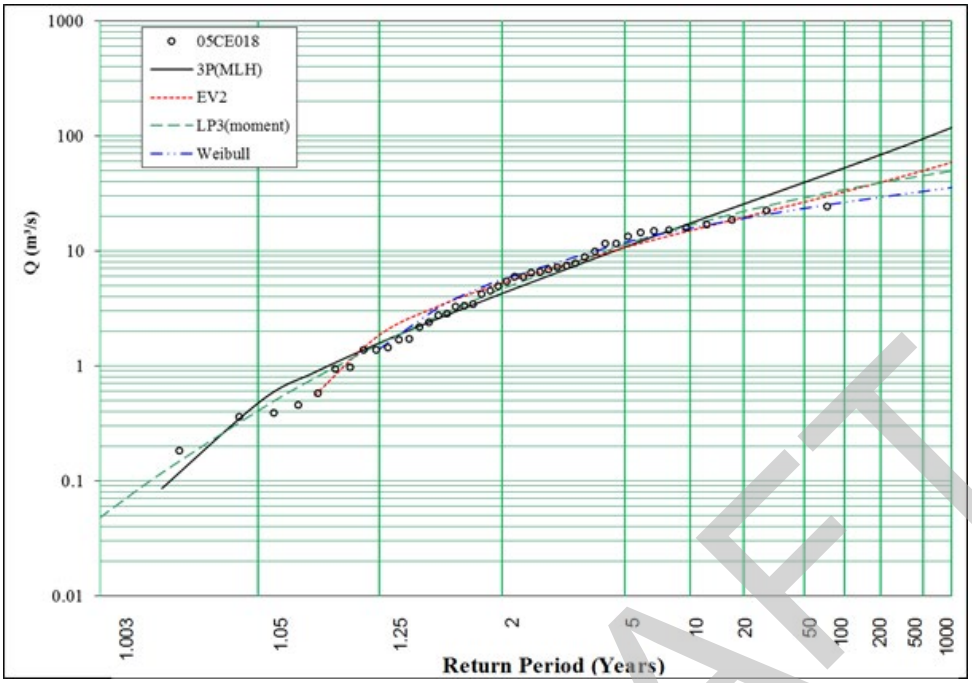
Ray Creek near Insfall (05CE010)

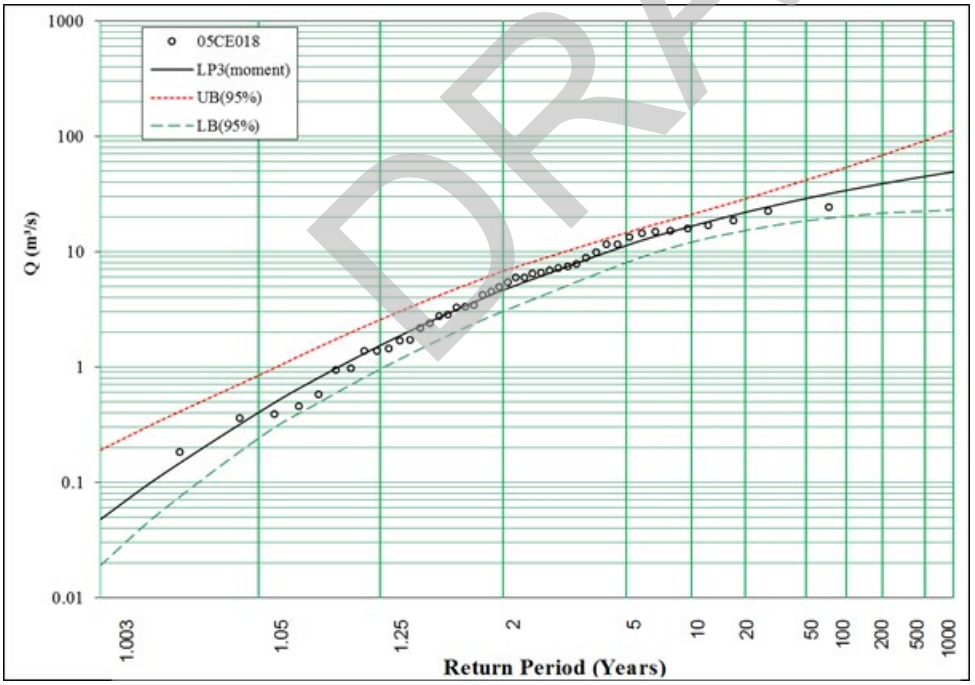




Return Period	3P	EV	LP3	Weibull
2	2	2	2	2
5	4	4	4	4
10	6	5	6	6
20	8	7	7	7
35	11	9	8	9
50	13	10	9	9
75	15	12	10	10
100	16	13	10	11
200	21	16	12	12
350	25	19	12	13
500	27	22	13	14
750	31	24	13	15
1000	34	27	14	15

Threehills Creek below Ray Creek (05CE018)

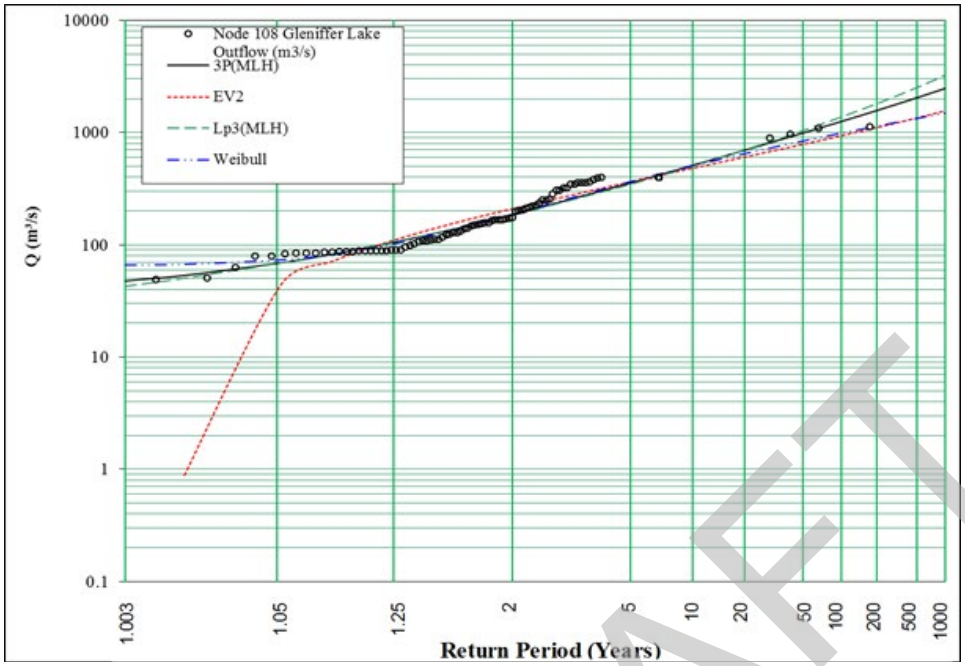


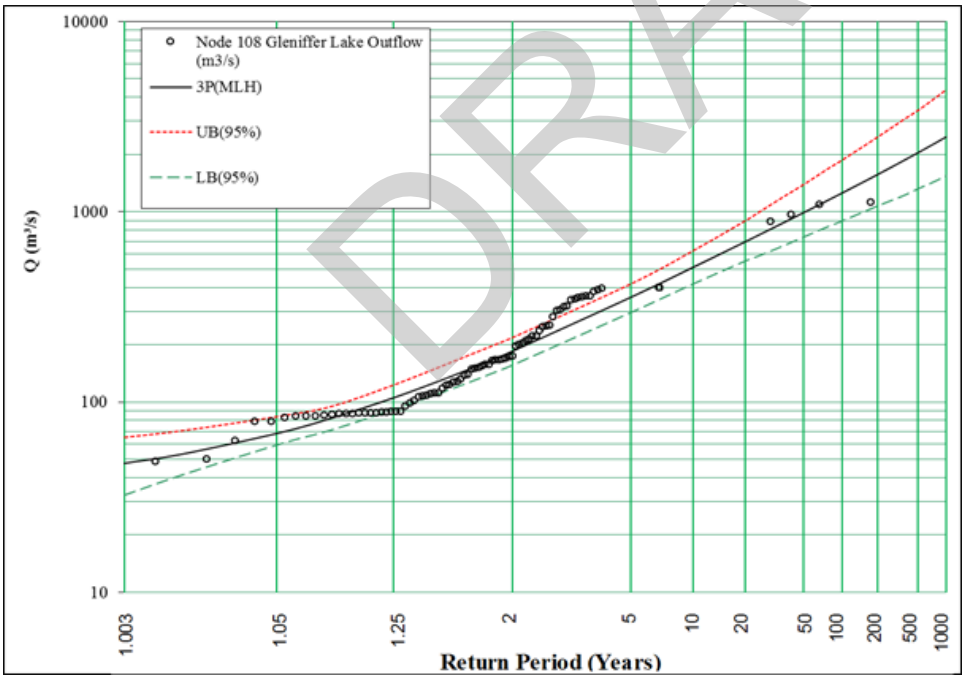


Return Period	3P	EV	LP3	Weibull
2	4	5	5	6
5	11	11	11	12
10	17	15	17	15
20	25	19	22	19
35	33	24	26	22
50	39	26	29	23
75	47	30	32	25
100	52	32	34	26
200	68	39	39	29
350	83	45	42	31
500	94	49	45	33
750	107	55	47	34
1000	117	58	49	35

C2.0 RESULTS FLOOD FREQUENCY ANALYSIS – REGULATED – BASED ON DAILY MAXIMUM FLOWS

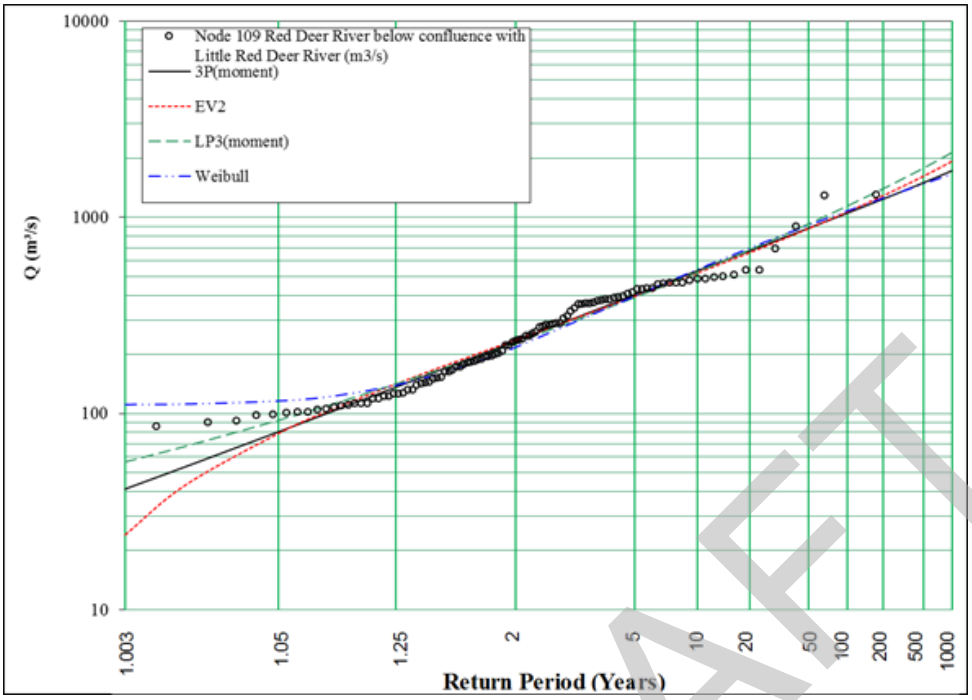
Red Deer River below Dickson Dam – Node 108

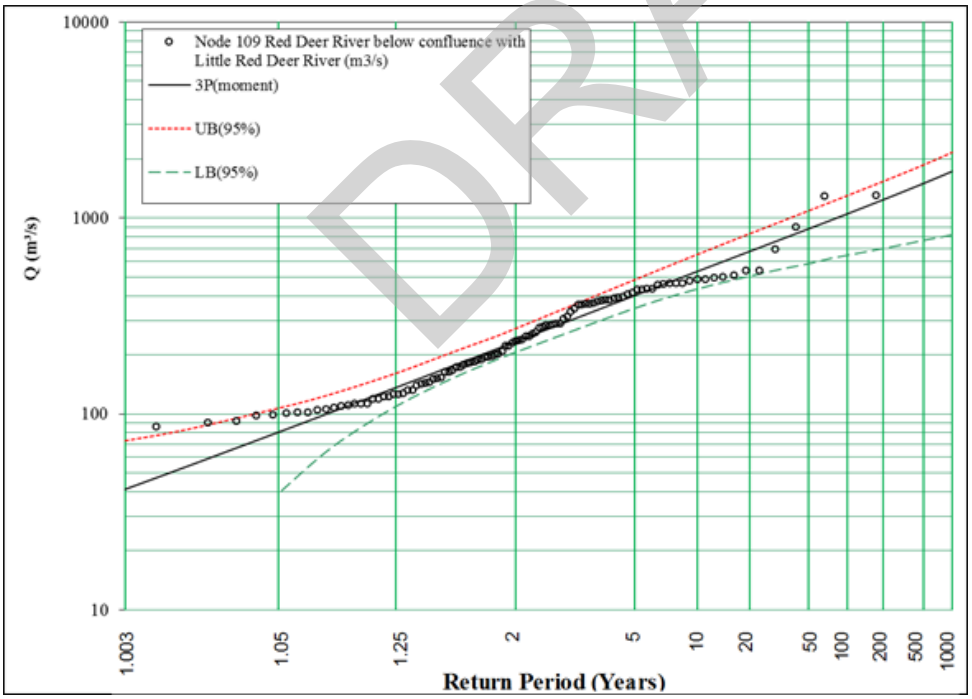




Return Period	3P	EV	LP3	Weibull
2	185	210	184	189
5	355	364	348	367
10	512	481	506	508
20	696	605	704	651
35	869	713	901	769
50	992	785	1048	845
75	1143	872	1236	931
100	1258	937	1386	993
200	1567	1104	1810	1143
350	1851	1250	2228	1265
500	2048	1350	2536	1343
750	2290	1470	2931	1432
1000	2473	1559	3244	1496

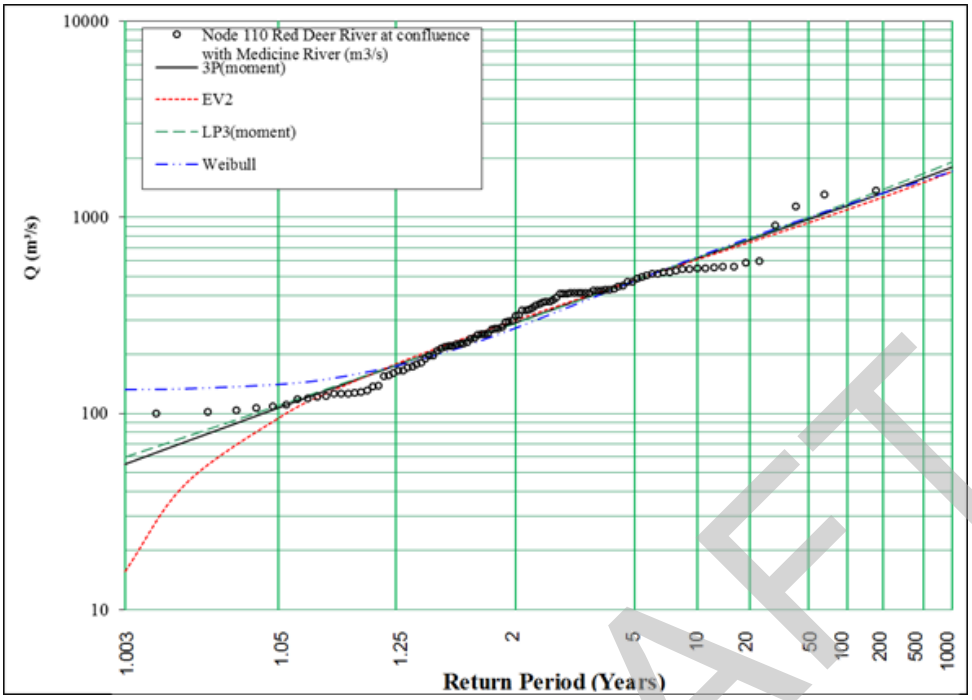
Red Deer River downstream of Little Red Deer River Confluence – Node 109

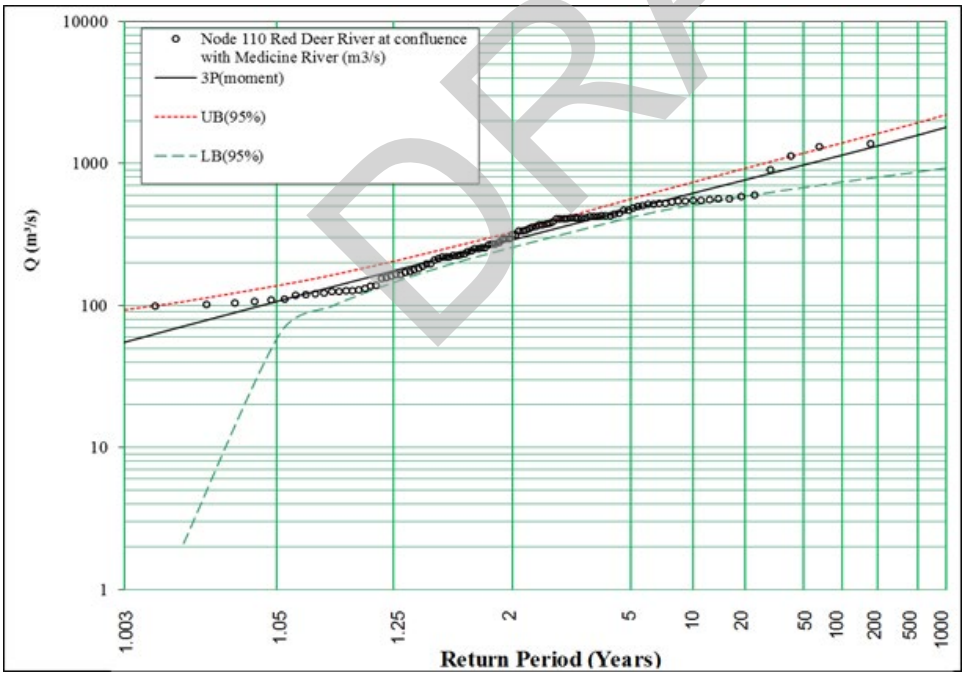




Return Period	3P	EV	LP3	Weibull
2	234	237	229	218
5	402	394	391	396
10	534	520	528	544
20	676	660	685	699
35	799	787	829	829
50	881	875	929	913
75	979	983	1054	1011
100	1052	1065	1148	1081
200	1236	1283	1401	1253
350	1397	1483	1633	1395
500	1504	1622	1795	1486
750	1632	1794	1994	1591
1000	1726	1924	2146	1666

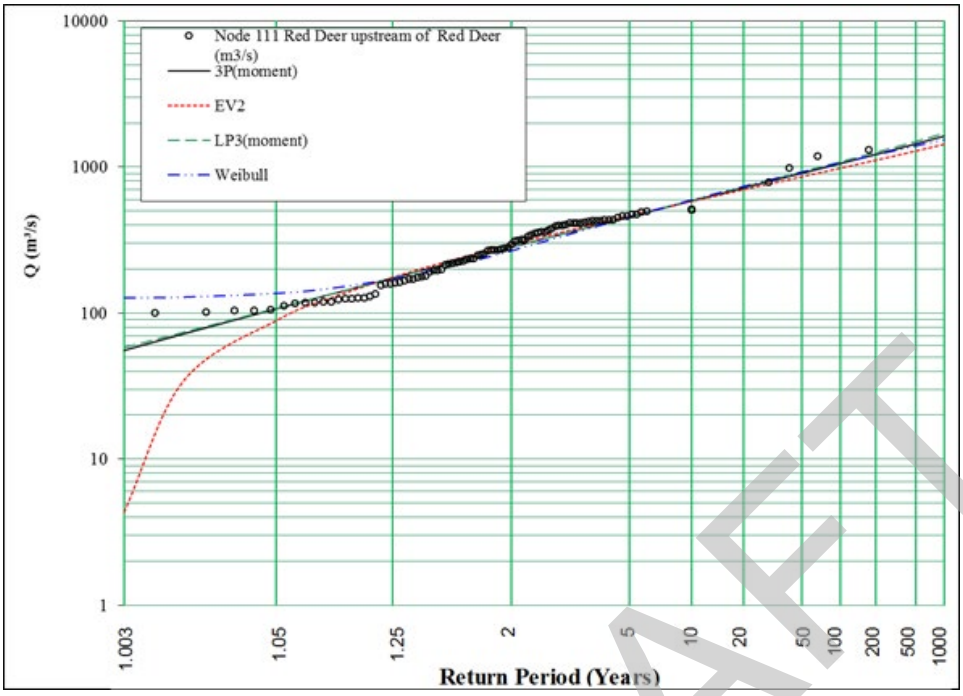
Red Deer River downstream of Medicine River Confluence – Node 110

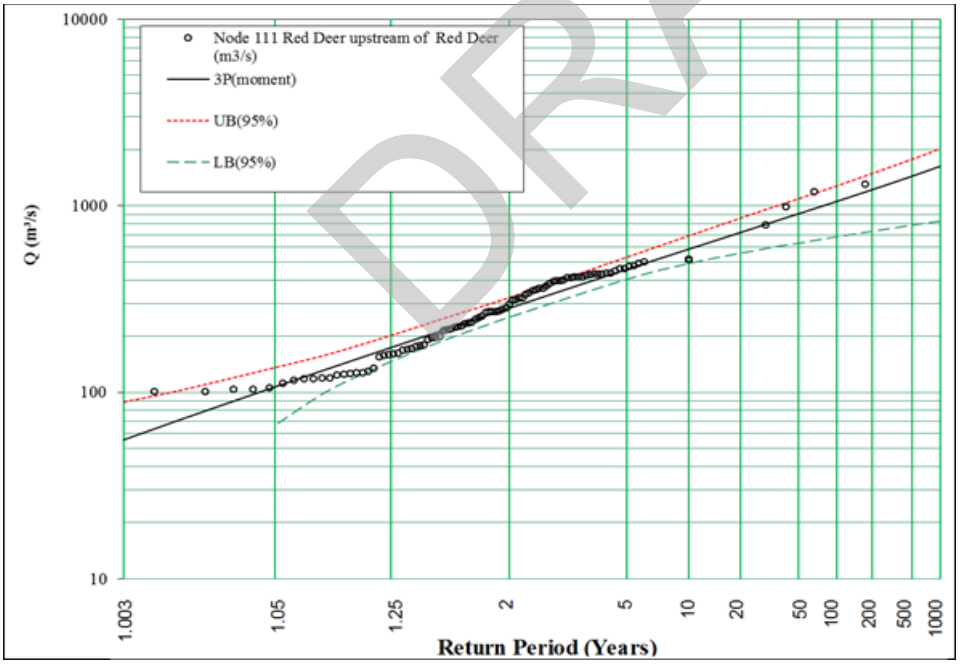




Return Period	3P	EV	LP3	Weibull
2	290	299	288	274
5	478	479	476	476
10	619	610	621	632
20	768	747	775	792
35	893	863	908	922
50	977	940	997	1005
75	1075	1031	1102	1101
100	1147	1097	1180	1168
200	1329	1267	1379	1333
350	1484	1413	1551	1467
500	1588	1510	1667	1552
750	1710	1626	1804	1650
1000	1799	1711	1905	1719

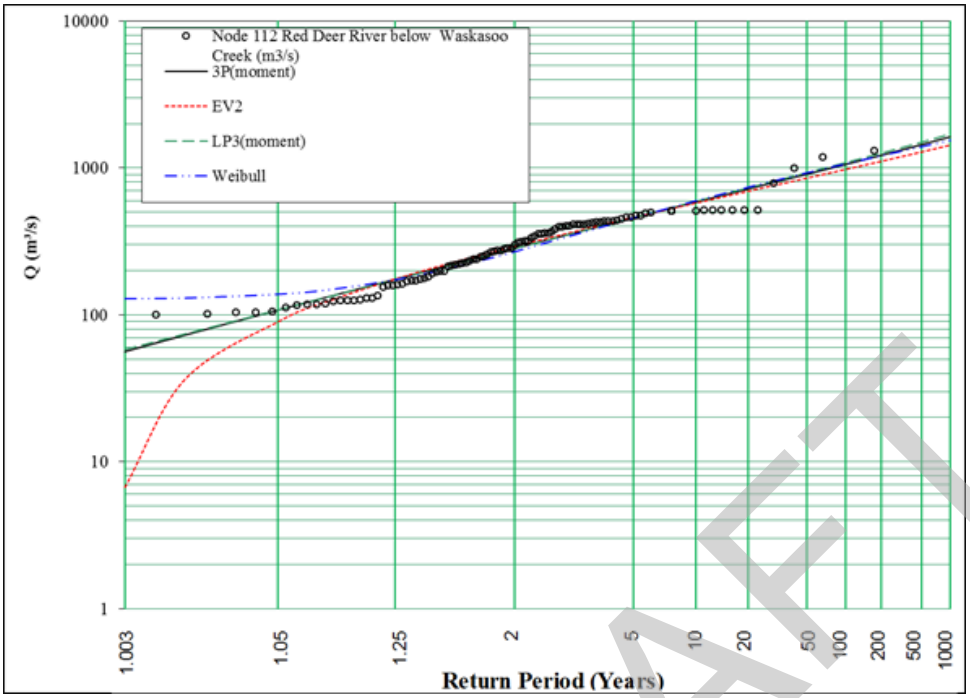
Red Deer River upstream of Red Deer – Node 111

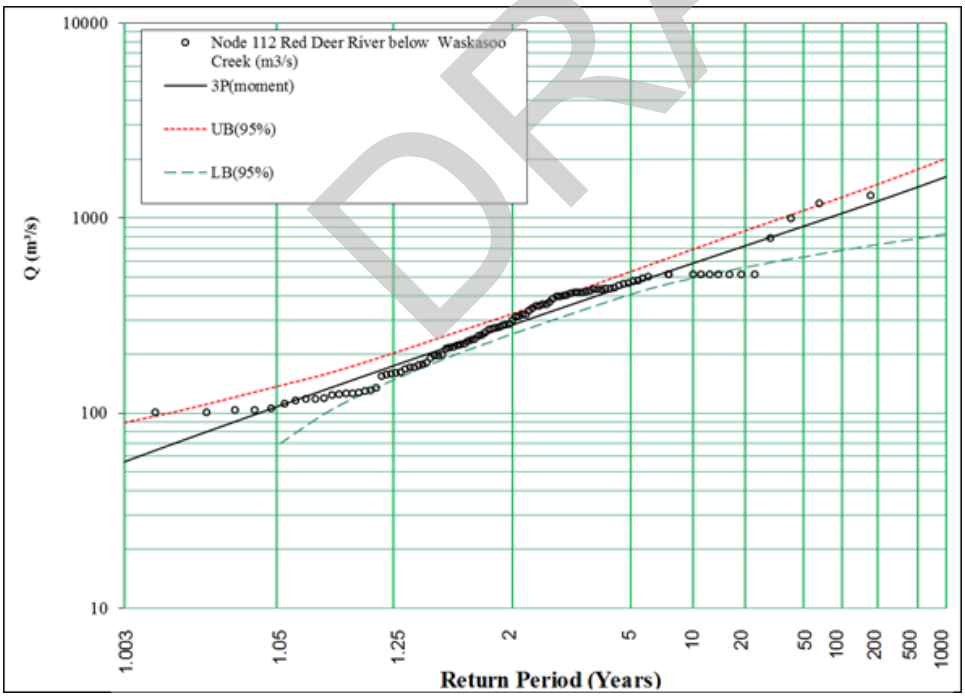




Return Period	3P	EV	LP3	Weibull
2	282	294	281	268
5	457	463	458	456
10	586	580	591	599
20	720	697	730	742
35	833	793	848	857
50	907	856	927	930
75	994	928	1019	1014
100	1058	979	1087	1073
200	1218	1108	1257	1217
350	1354	1214	1403	1332
500	1444	1284	1501	1406
750	1550	1365	1615	1490
1000	1627	1423	1699	1549

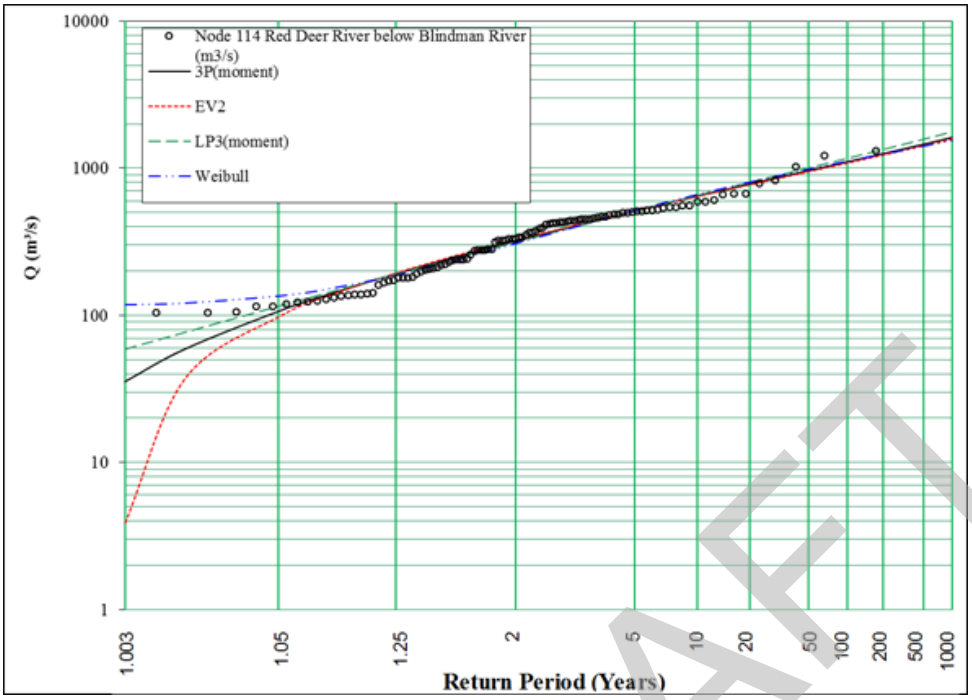
Red Deer River below Waskasoo and above Blindman River – Node 112/113

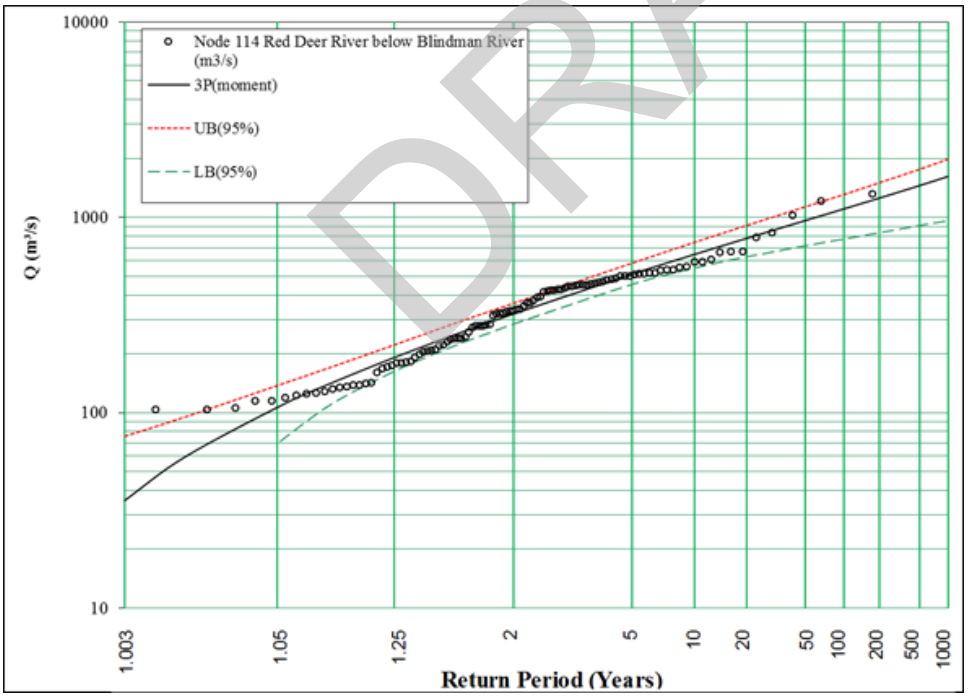




Return Period	3P	EV	LP3	Weibull
2	283	295	282	269
5	458	464	459	457
10	587	581	592	600
20	721	699	731	743
35	834	796	849	858
50	908	859	927	931
75	995	932	1019	1015
100	1059	985	1086	1074
200	1219	1115	1256	1217
350	1355	1224	1401	1333
500	1445	1295	1498	1407
750	1550	1378	1612	1490
1000	1628	1437	1695	1550

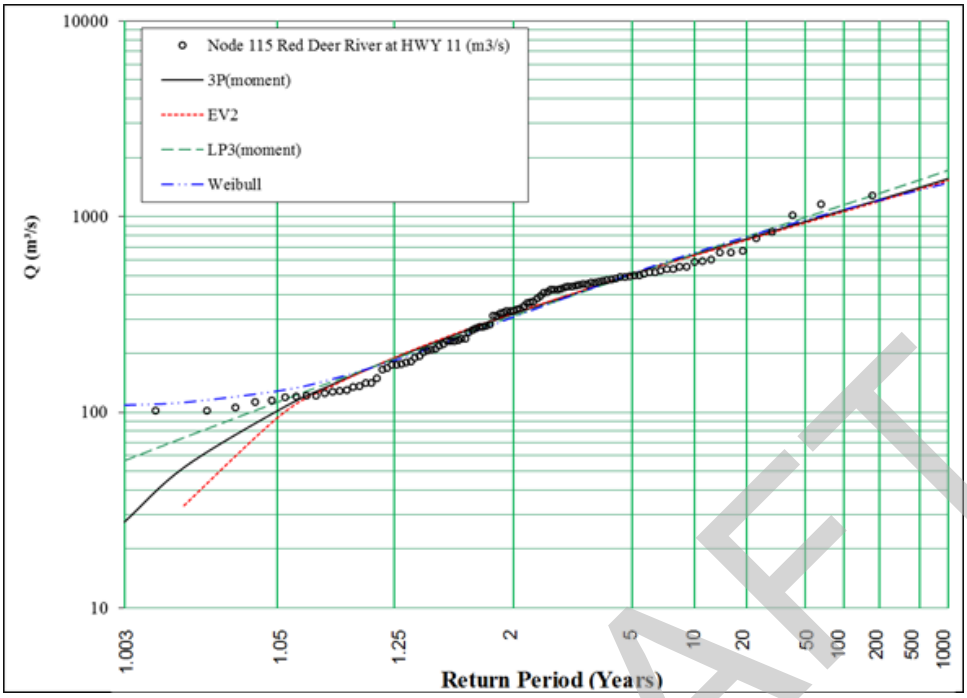
Red Deer River below Blindman River Confluence – Node 114

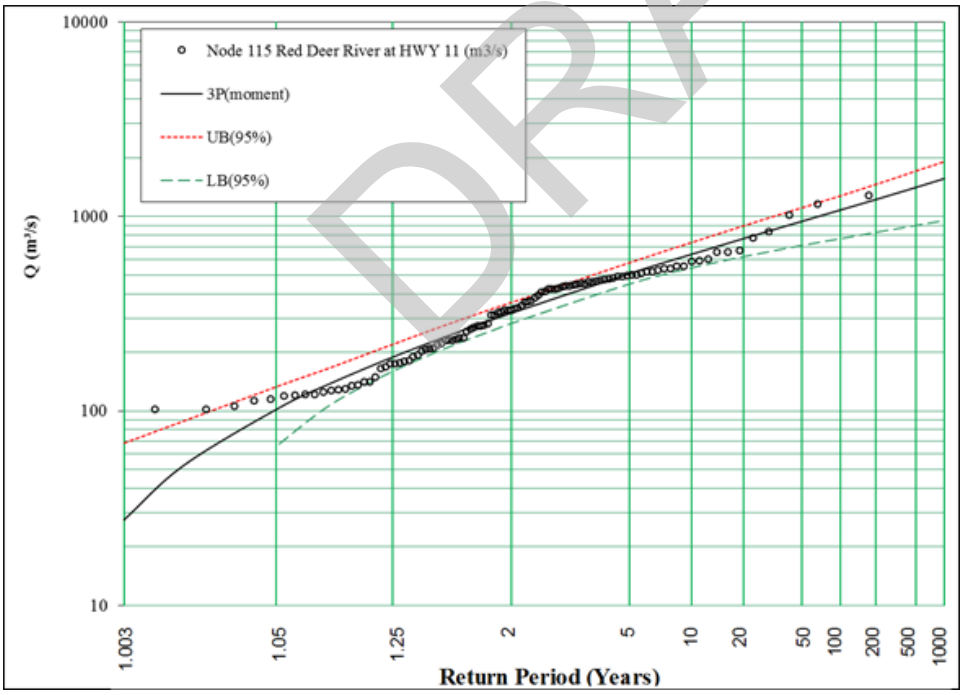




Return Period	3P	EV	LP3	Weibull
2	320	325	314	307
5	512	512	510	515
10	647	643	655	661
20	782	772	803	802
35	892	879	926	912
50	964	948	1007	982
75	1046	1028	1101	1059
100	1106	1085	1169	1114
200	1254	1227	1339	1244
350	1377	1346	1482	1347
500	1458	1423	1576	1412
750	1551	1513	1686	1486
1000	1619	1578	1766	1538

Red Deer River at Highway 11 – Node 115





Return Period	3P	EV	LP3	Weibull
2	318	323	310	306
5	508	508	506	512
10	640	636	648	654
20	770	763	794	789
35	876	866	915	894
50	945	933	994	960
75	1024	1010	1086	1034
100	1080	1066	1152	1085
200	1220	1202	1318	1208
350	1336	1315	1456	1304
500	1412	1388	1547	1365
750	1500	1473	1653	1434
1000	1563	1534	1730	1482

C3.0 RESULTS FLOOD FREQUENCY ANALYSIS – REGULATED – BASED ON SYNTHETIC HYDROGRAPHS ROUTING

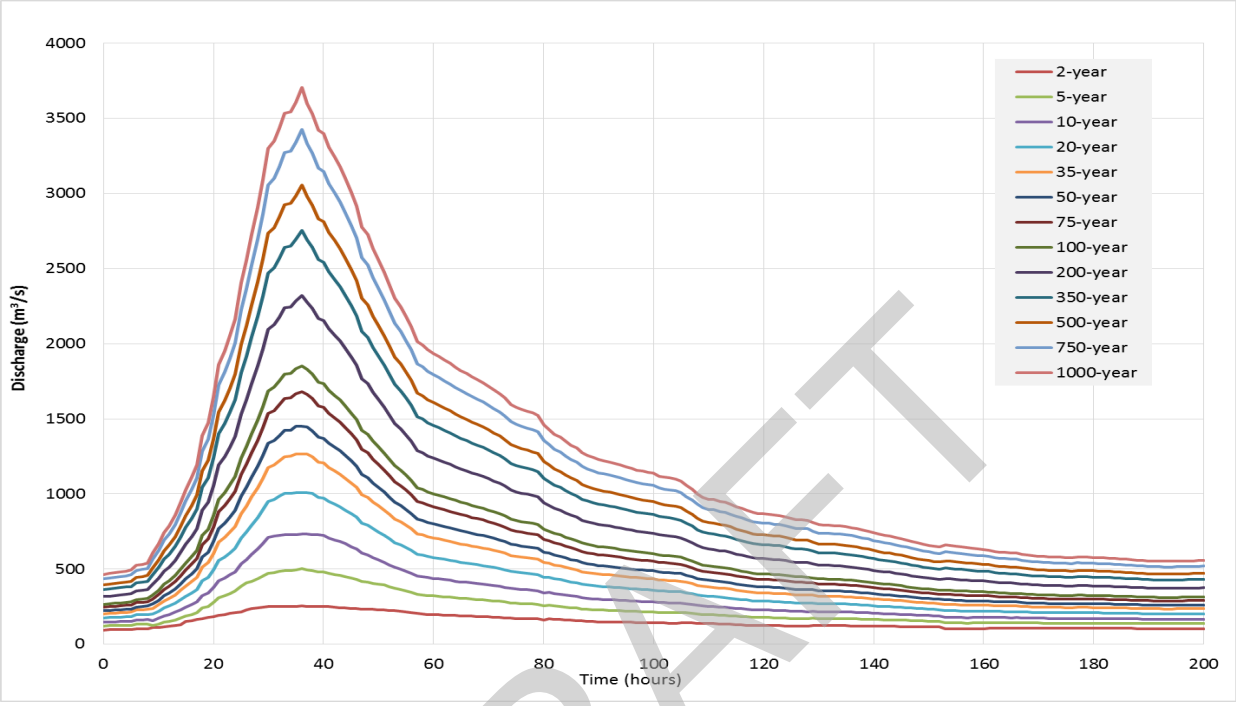


Figure C.3-1: Inflow Flood Hydrographs to Gleniffer Reservoir

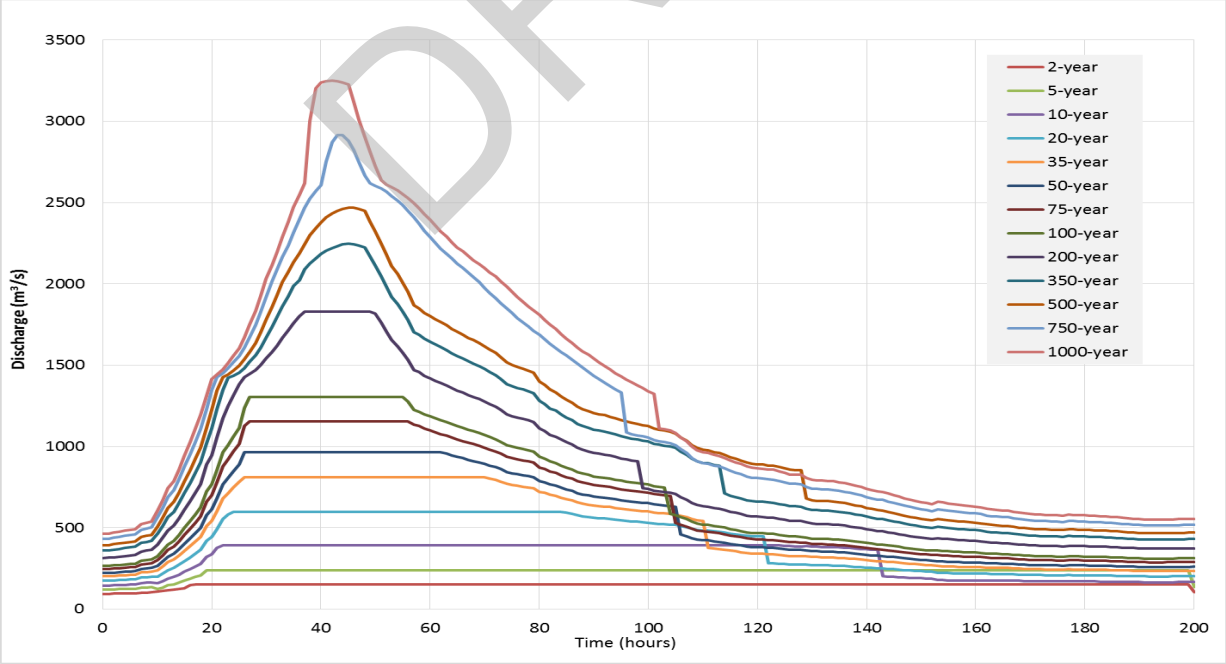


Figure C.3-2: Outflow Flood Hydrographs from Gleniffer Reservoir

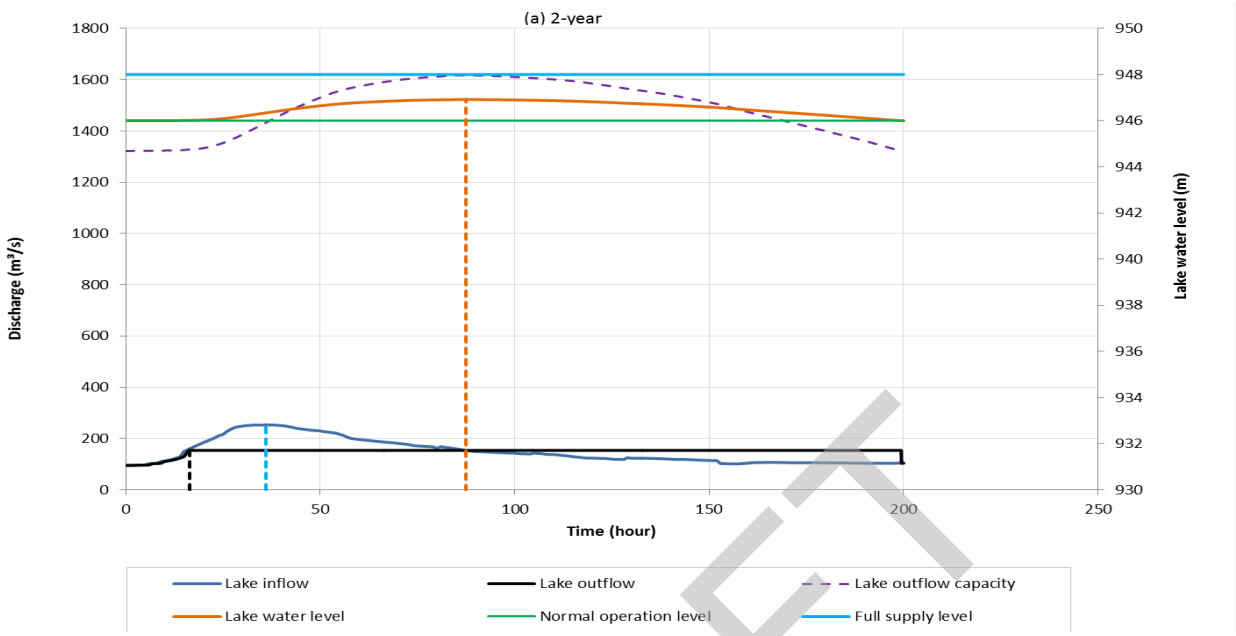


Figure C.3-3a: Comparison Inflow, Outflow, and Water Level Hydrographs - Starting Reservoir Level = 946 m

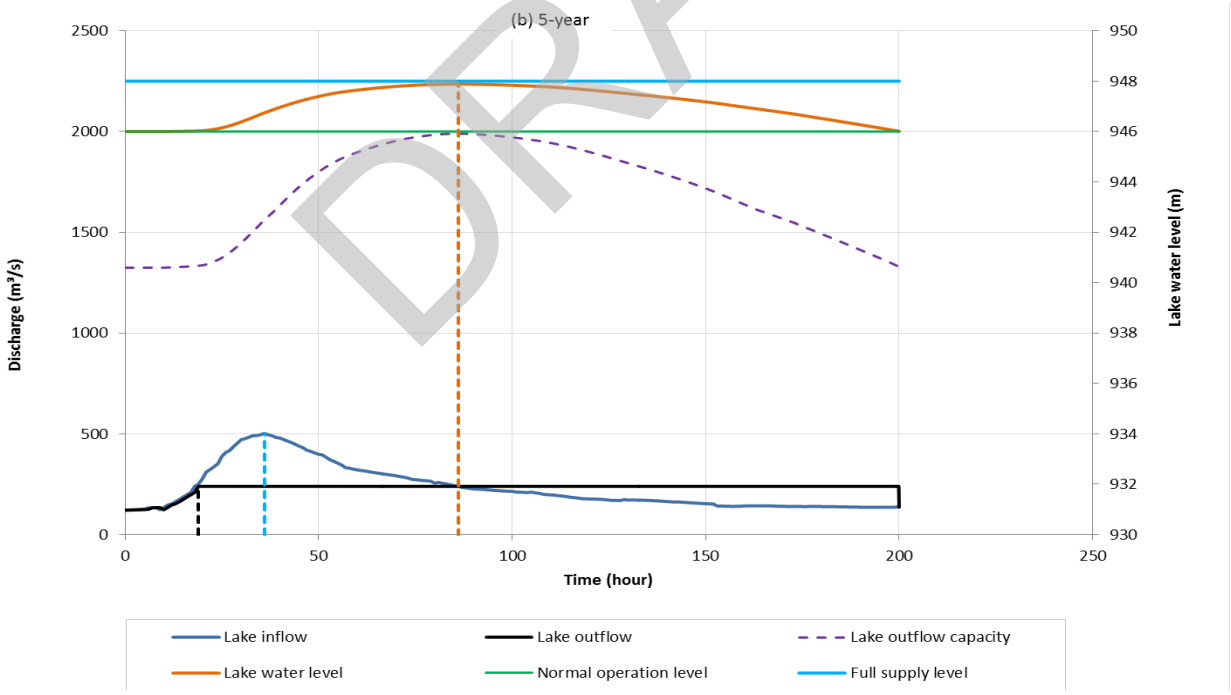


Figure C.3-3b: Comparison Inflow, Outflow, and Water Level Hydrographs - Starting Reservoir Level = 946 m

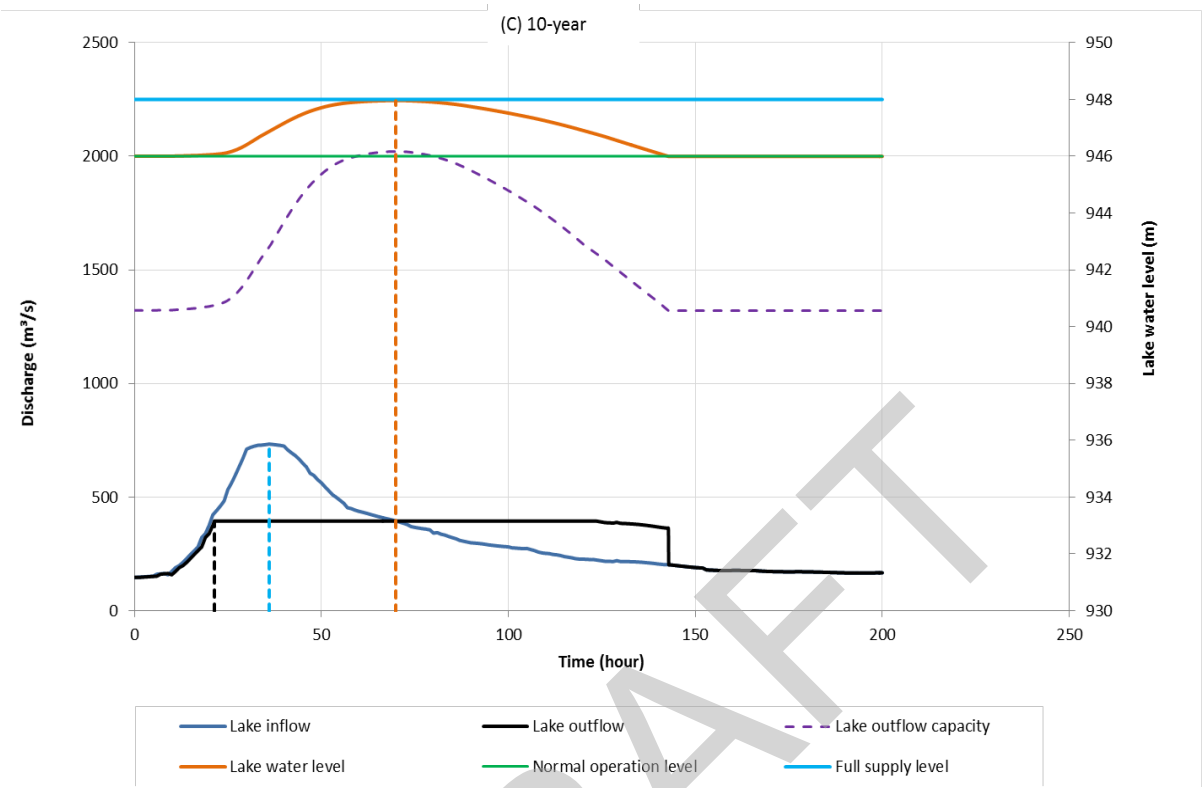


Figure C.3-3c: Comparison Inflow, Outflow, and Water Level Hydrographs - Starting Reservoir Level = 946 m

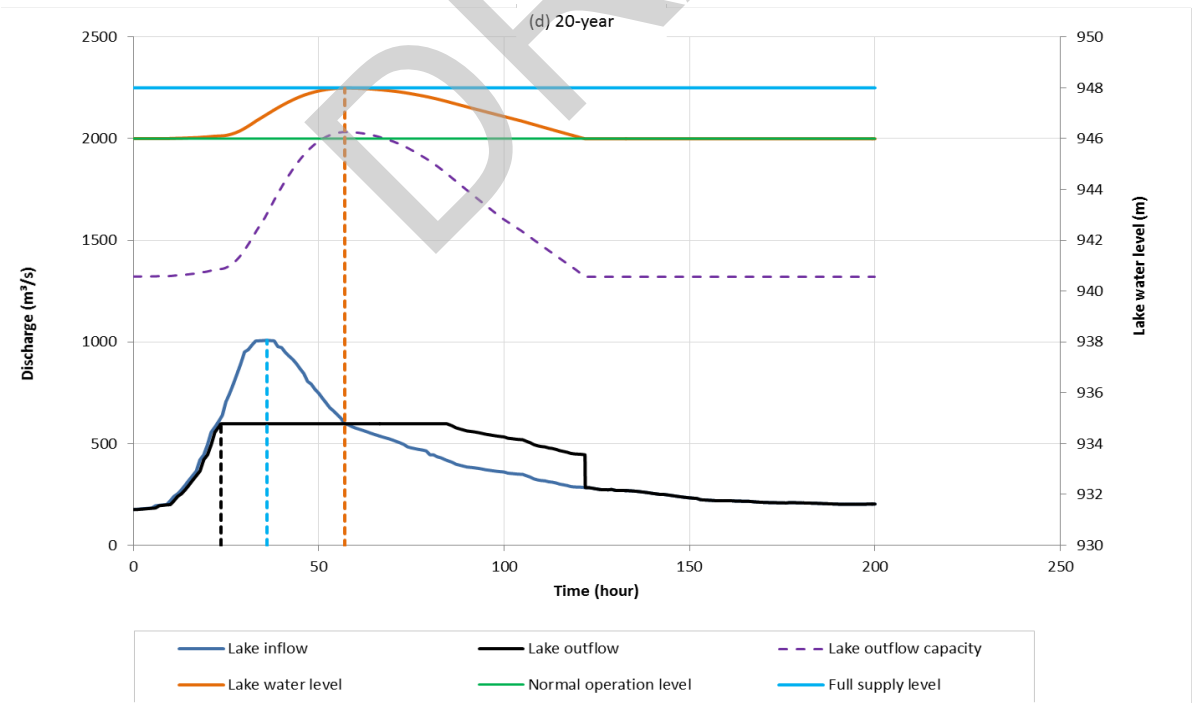


Figure C.3-3d: Comparison Inflow, Outflow, and Water Level Hydrographs - Starting Reservoir Level = 946 m

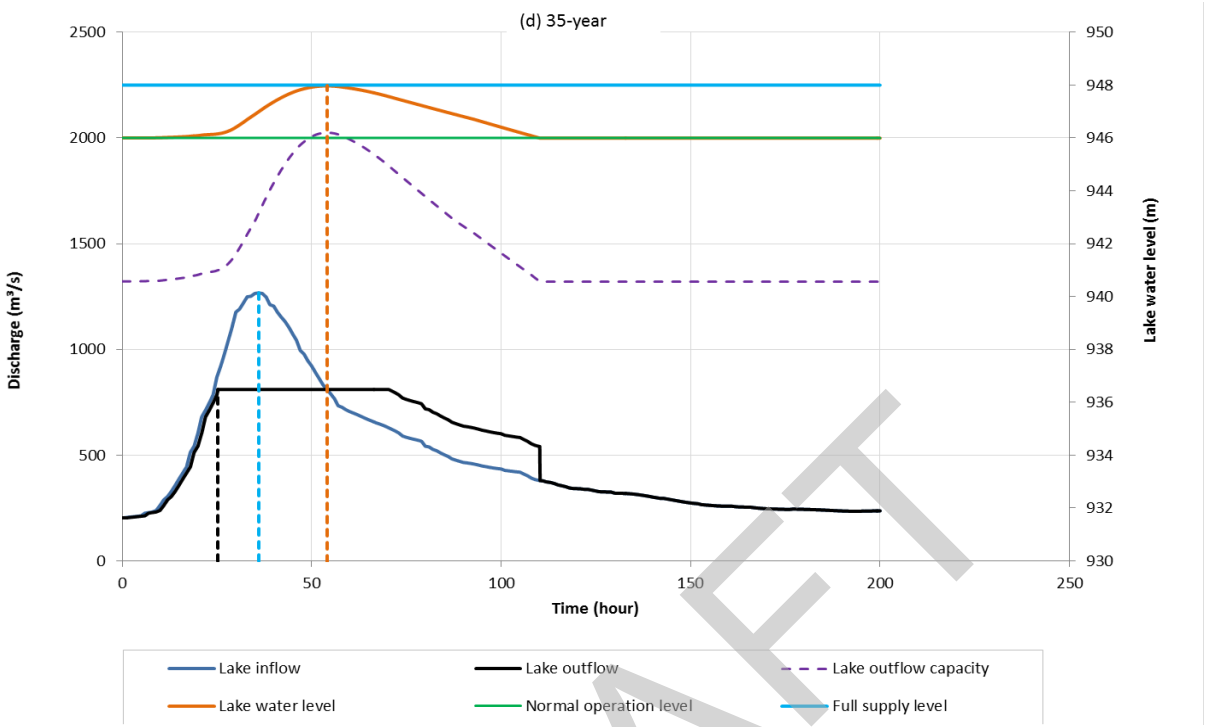


Figure C.3-3d: Comparison Inflow, Outflow, and Water Level Hydrographs - Starting Reservoir Level = 946 m

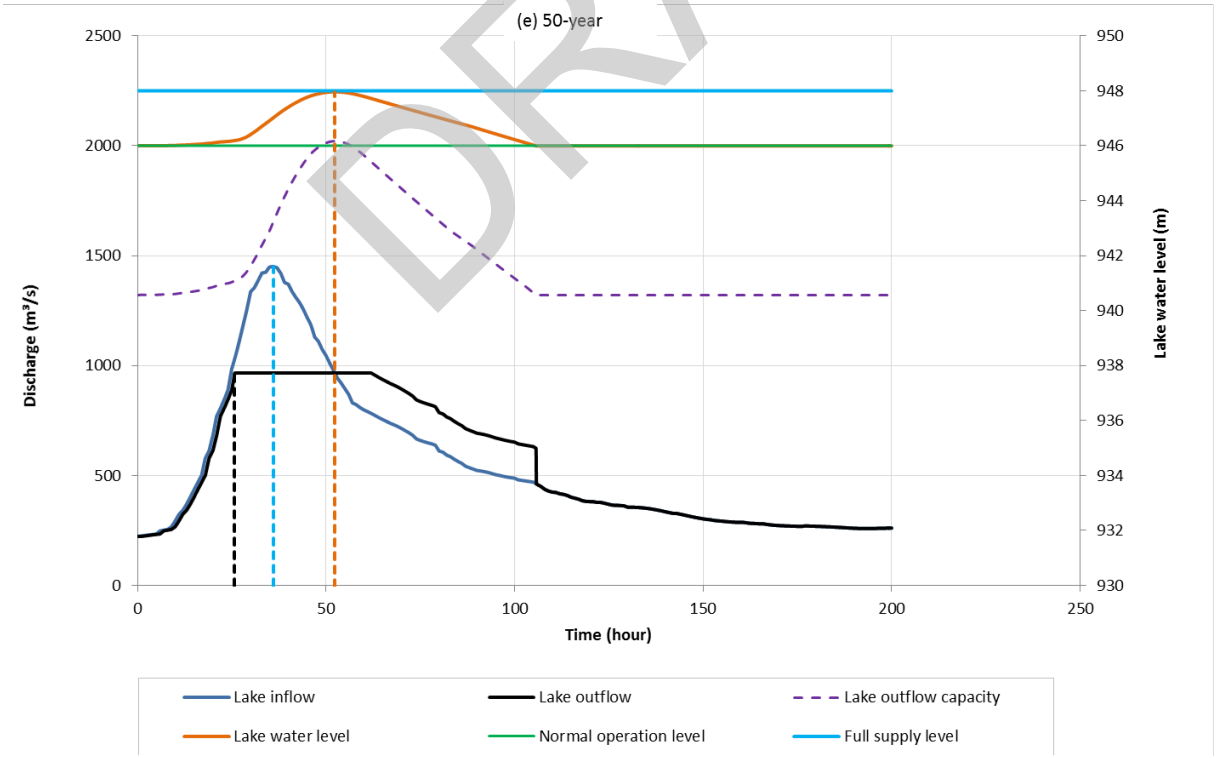


Figure C.3-3e: Comparison Inflow, Outflow, and Water Level Hydrographs - Starting Reservoir Level = 946 m

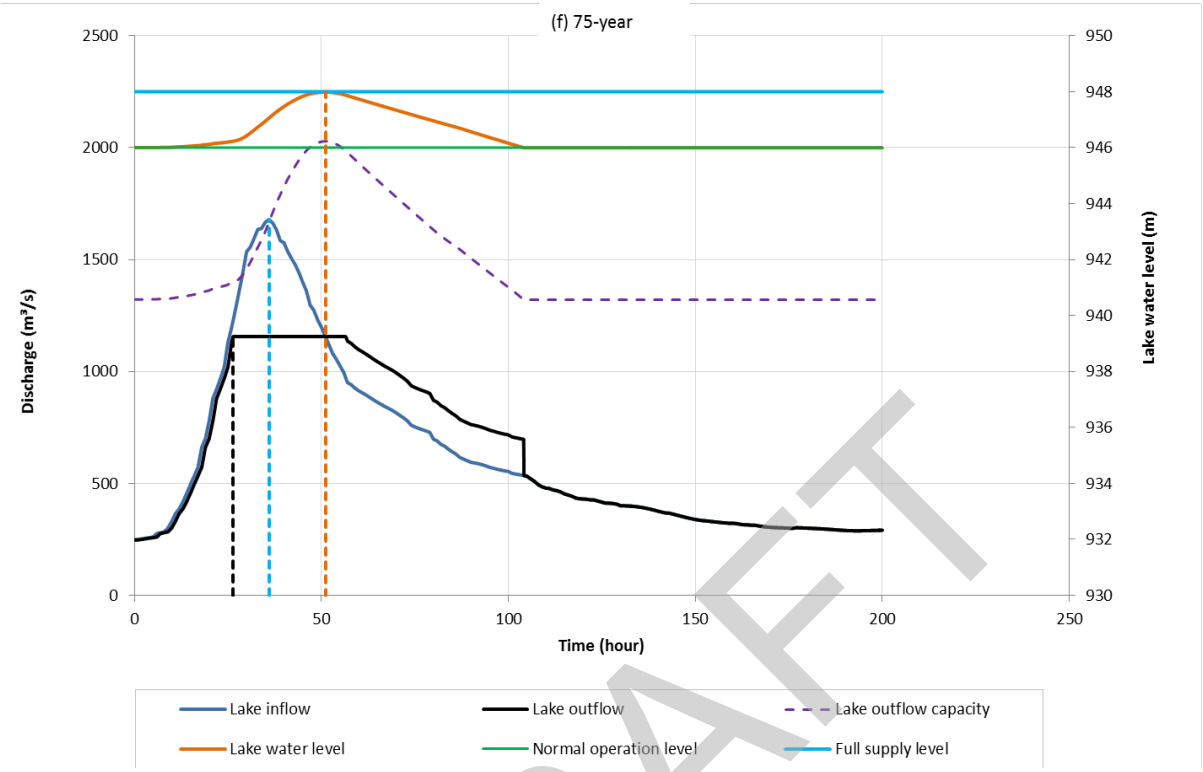


Figure C.3-3f: Comparison Inflow, Outflow, and Water Level Hydrographs - Starting Reservoir Level = 946 m

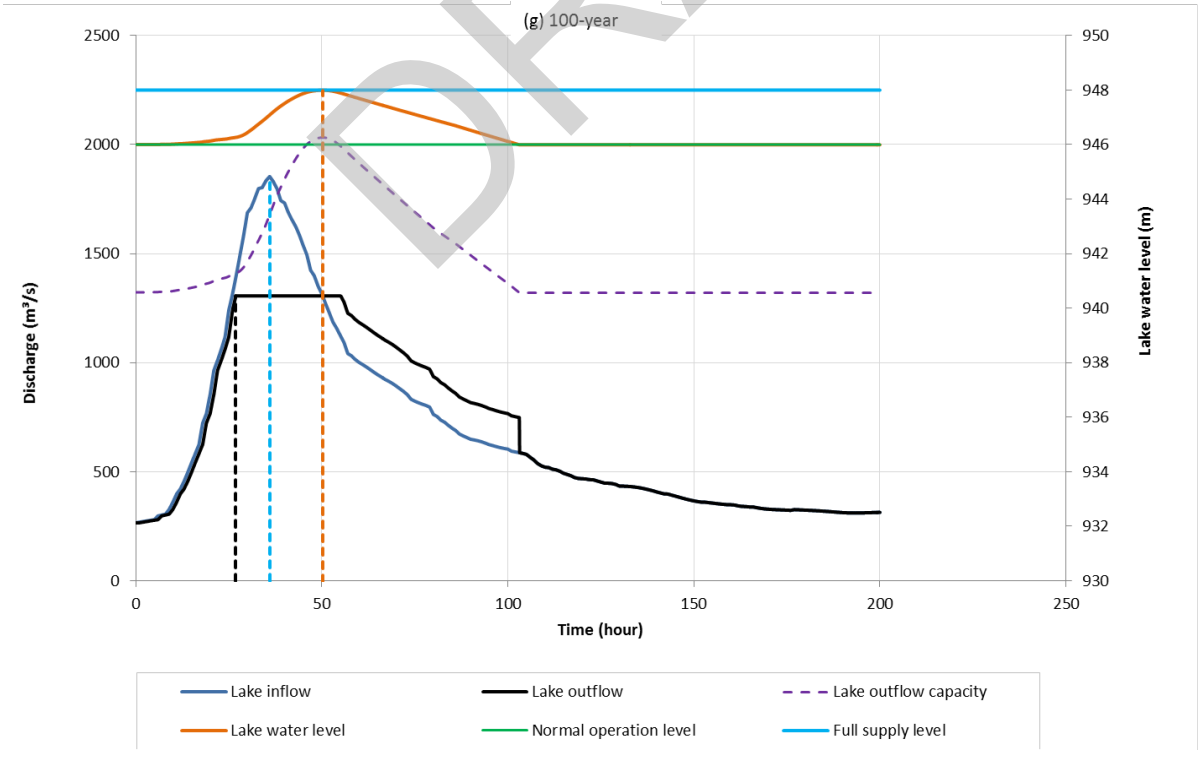


Figure C.3-3g: Comparison Inflow, Outflow, and Water Level Hydrographs - Starting Reservoir Level = 946 m

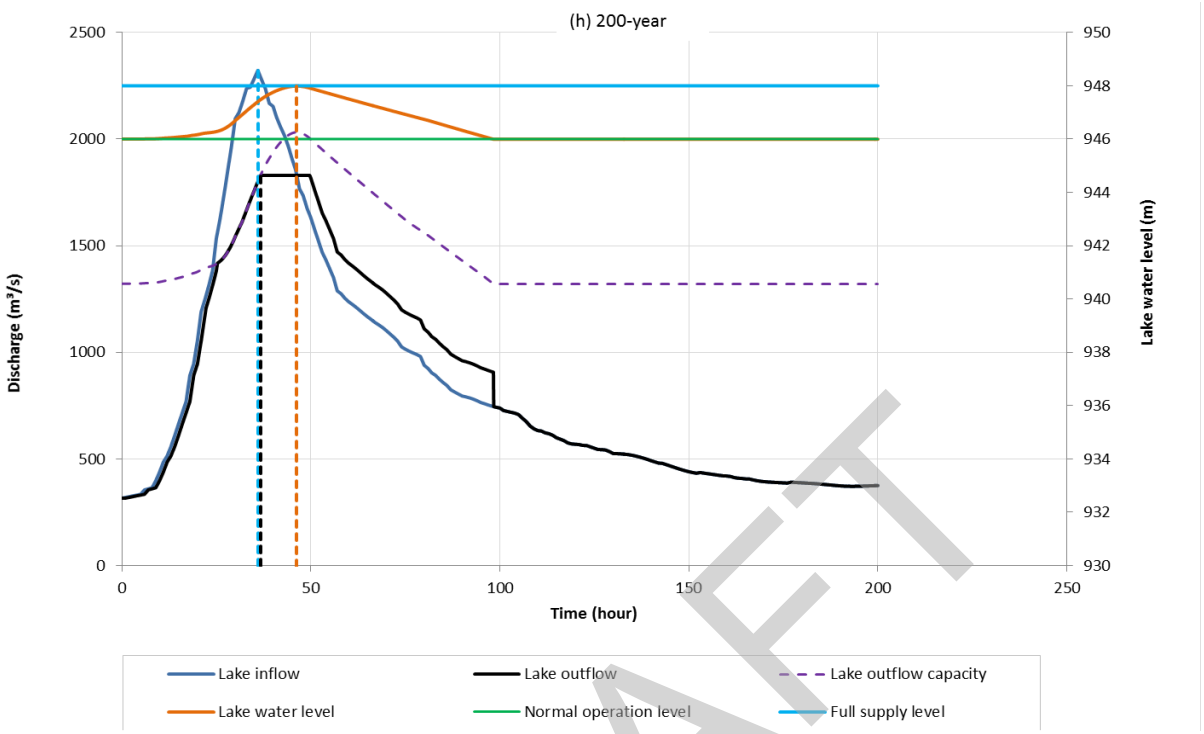


Figure C.3-3h: Comparison Inflow, Outflow, and Water Level Hydrographs - Starting Reservoir Level = 946 m

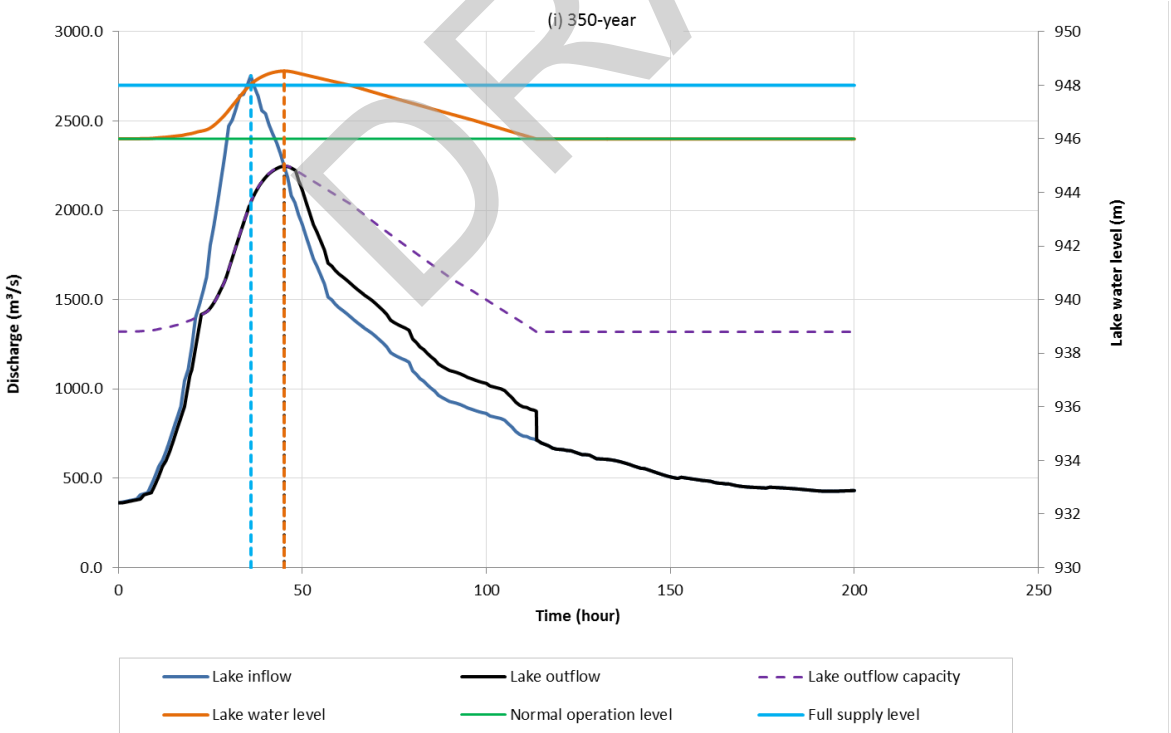


Figure C.3-3i: Comparison Inflow, Outflow, and Water Level Hydrographs - Starting Reservoir Level = 946 m

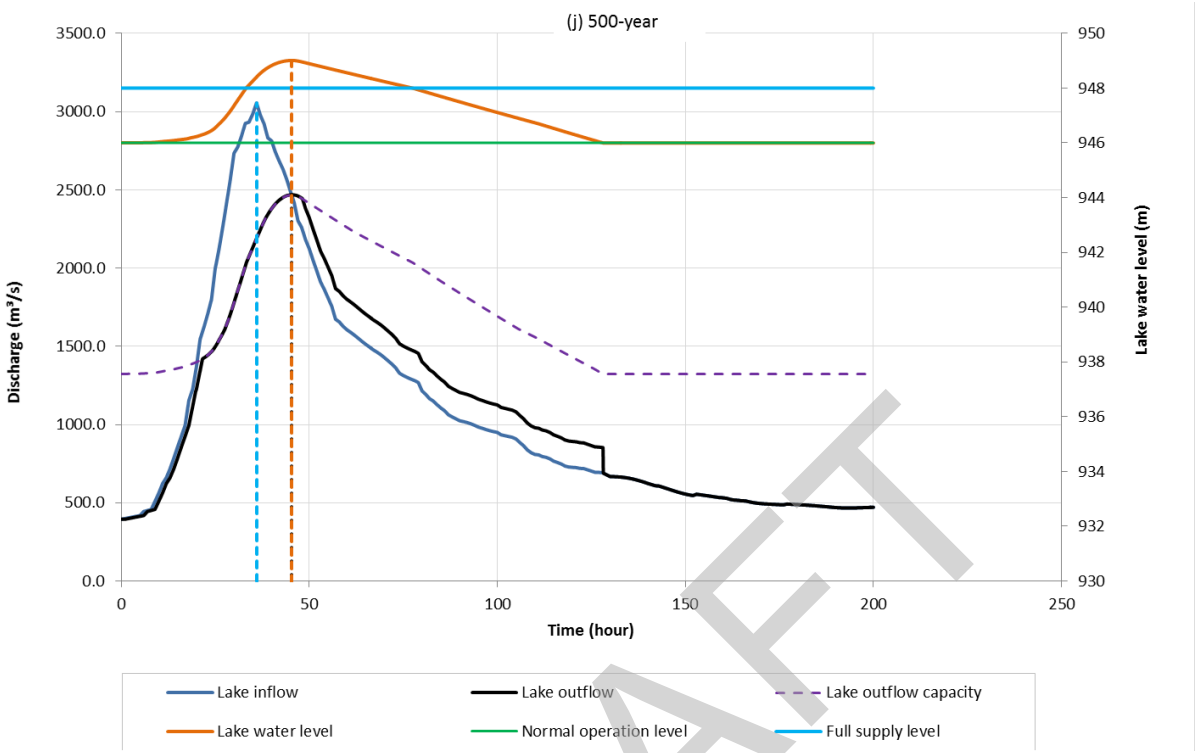


Figure C.3-3j: Comparison Inflow, Outflow, and Water Level Hydrographs - Starting Reservoir Level = 946 m

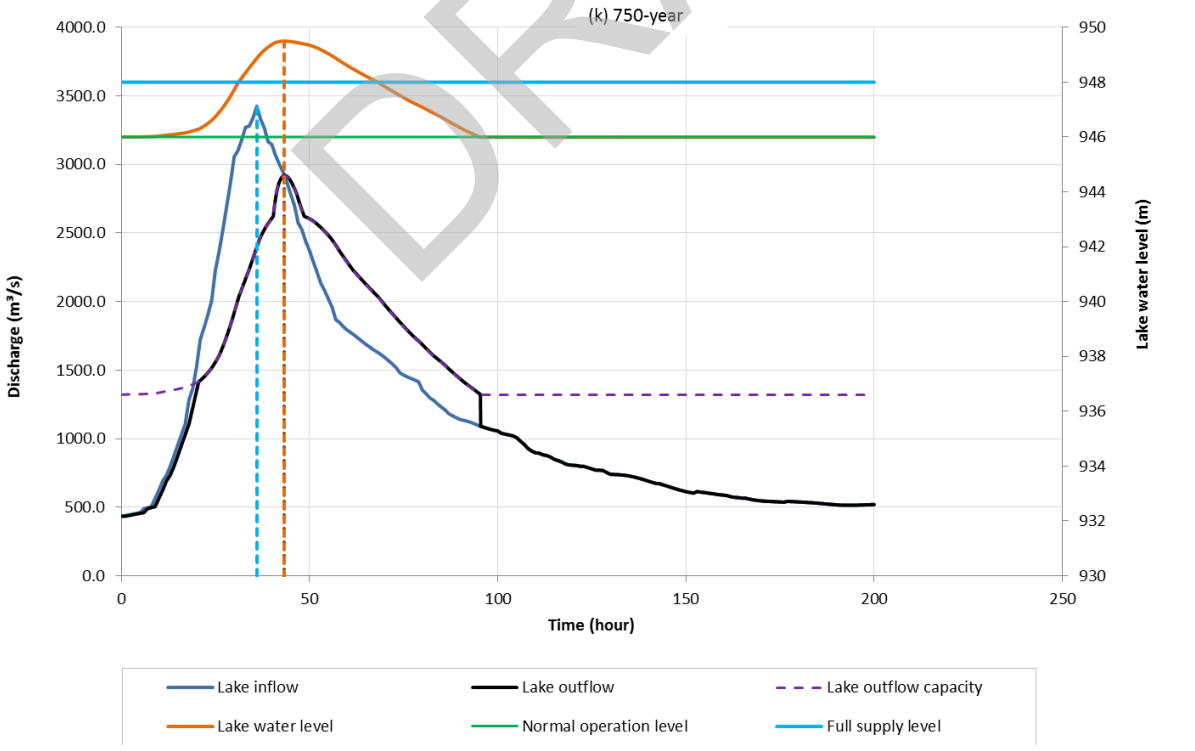


Figure C.3-3k: Comparison Inflow, Outflow, and Water Level Hydrographs - Starting Reservoir Level = 946 m

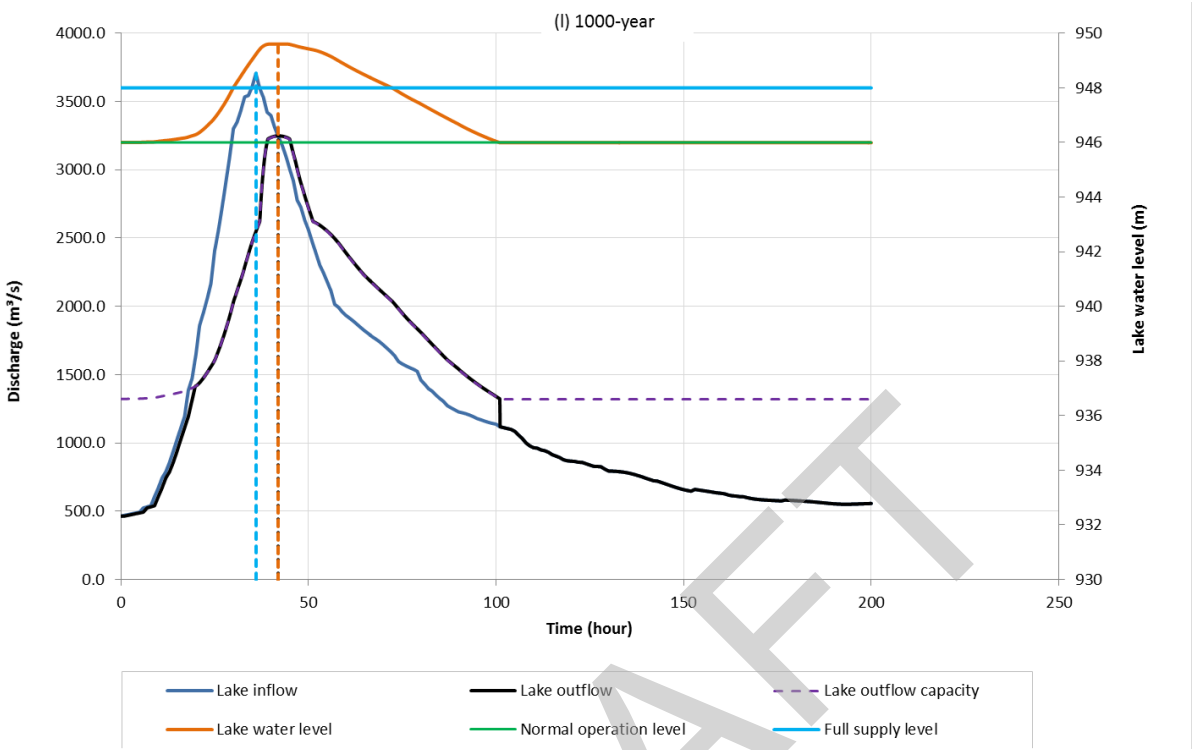


Figure C.3-3l: Comparison Inflow, Outflow, and Water Level Hydrographs - Starting Reservoir Level = 946 m

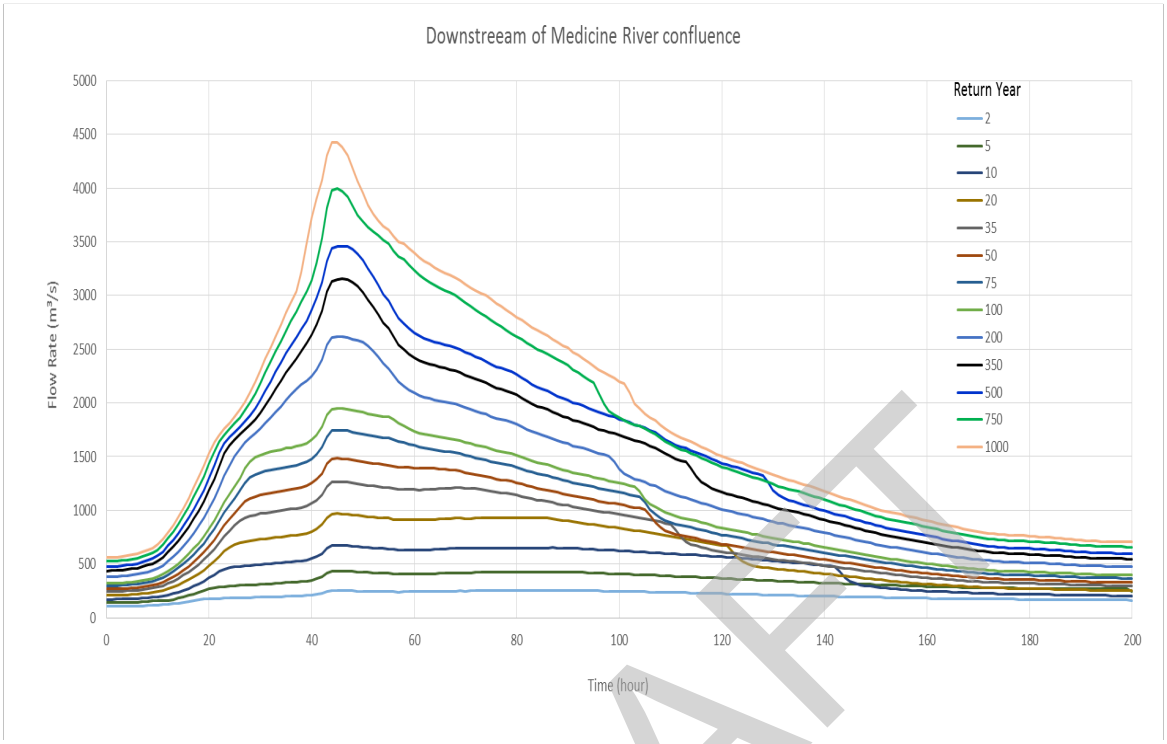


Figure C.3-4: Flood Hydrographs for Red Deer River below Medicine River

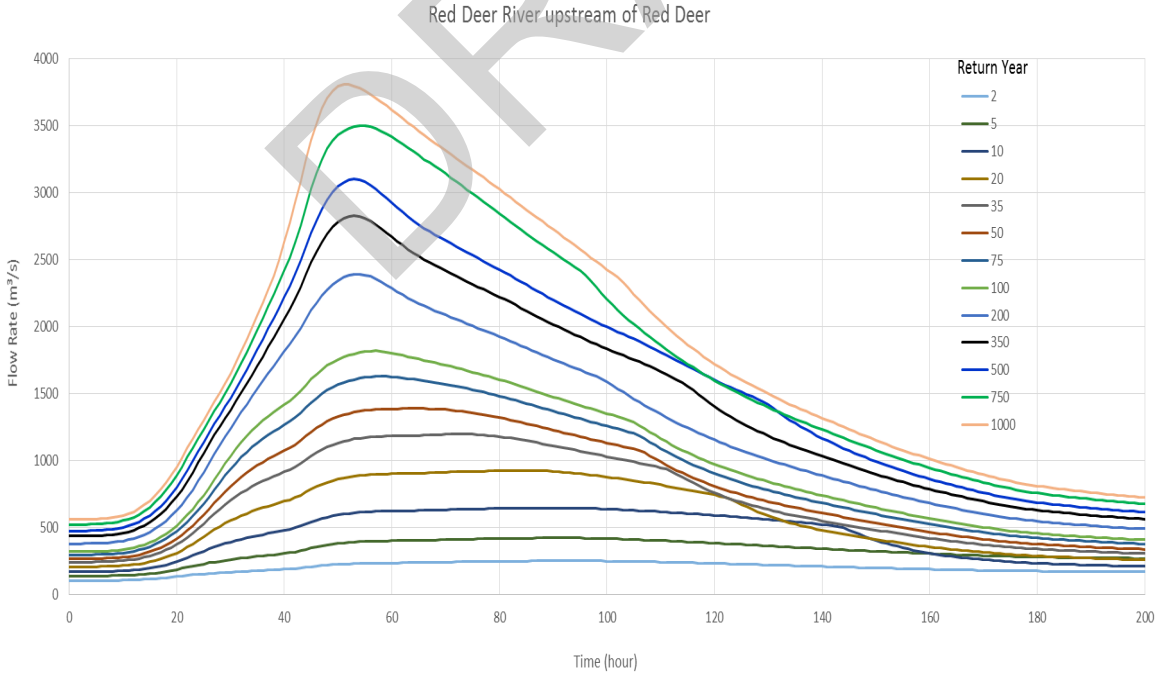


Figure C.3-5: Flood Hydrographs for Red Deer River upstream of Red Deer

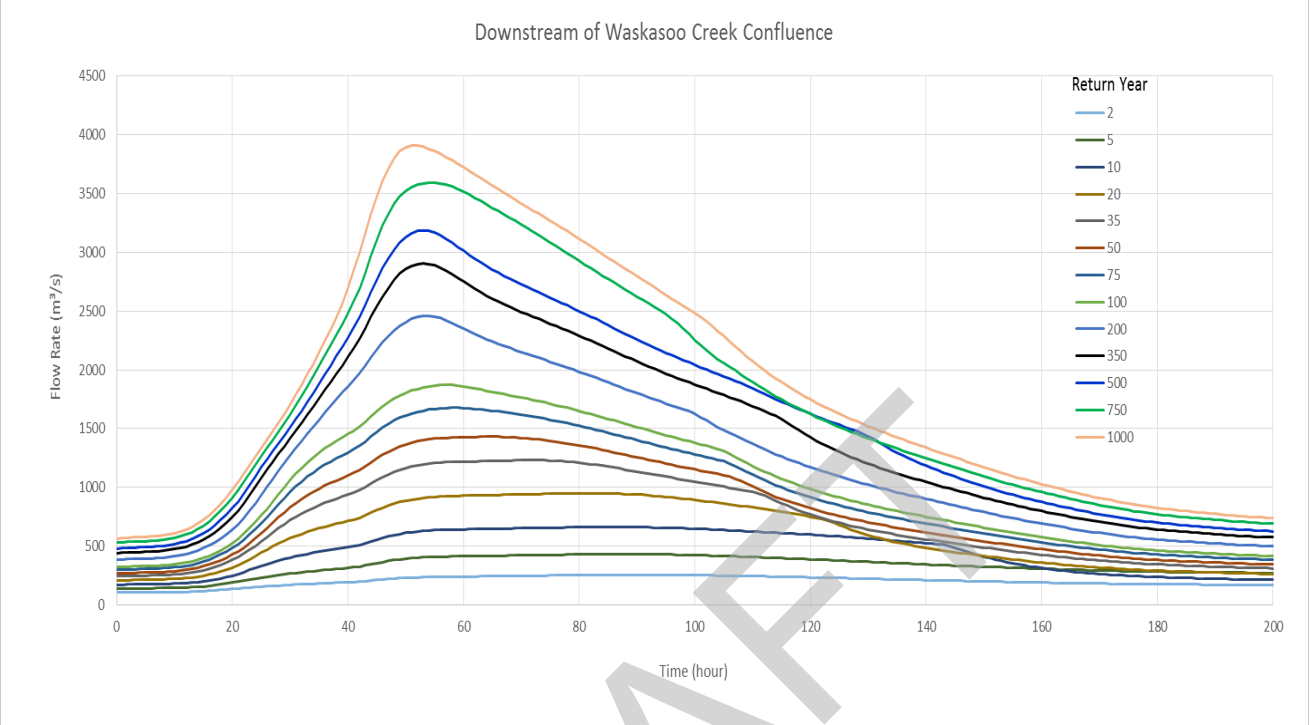


Figure C.3-6: Flood Hydrographs for Red Deer River downstream of Waskasoo Creek Confluence

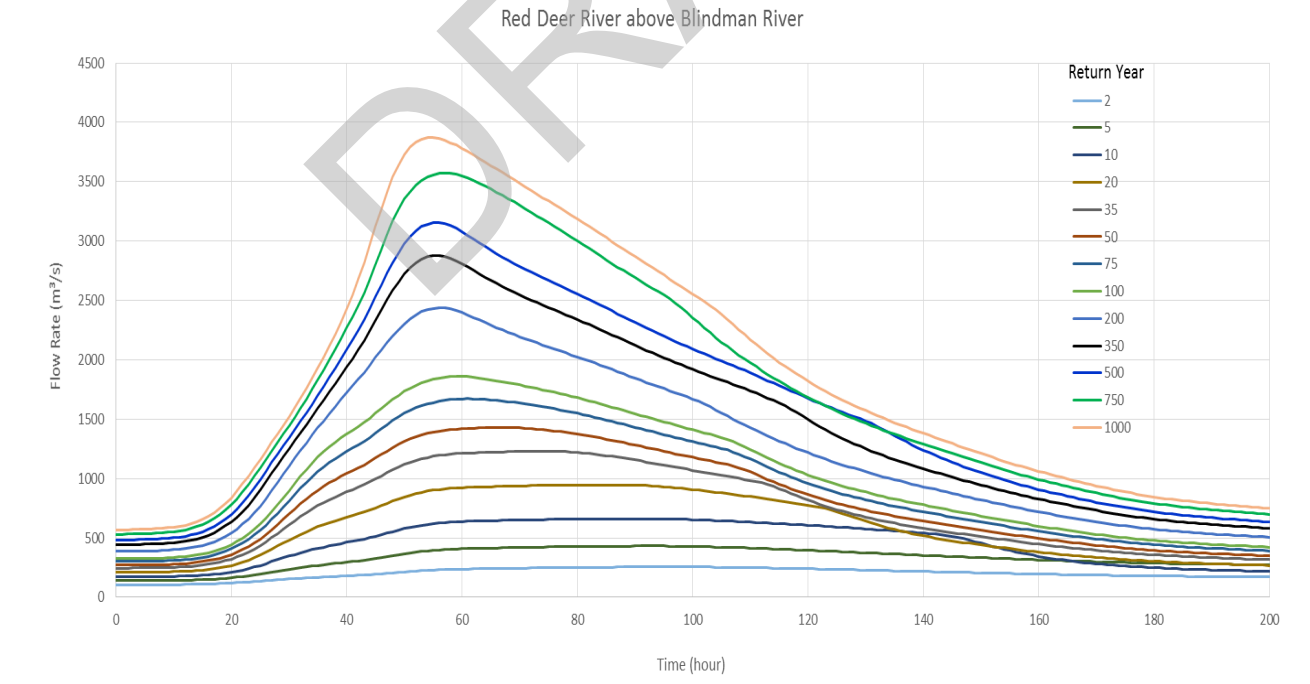


Figure C.3-7: Flood Hydrographs for Red Deer River above Blindman River

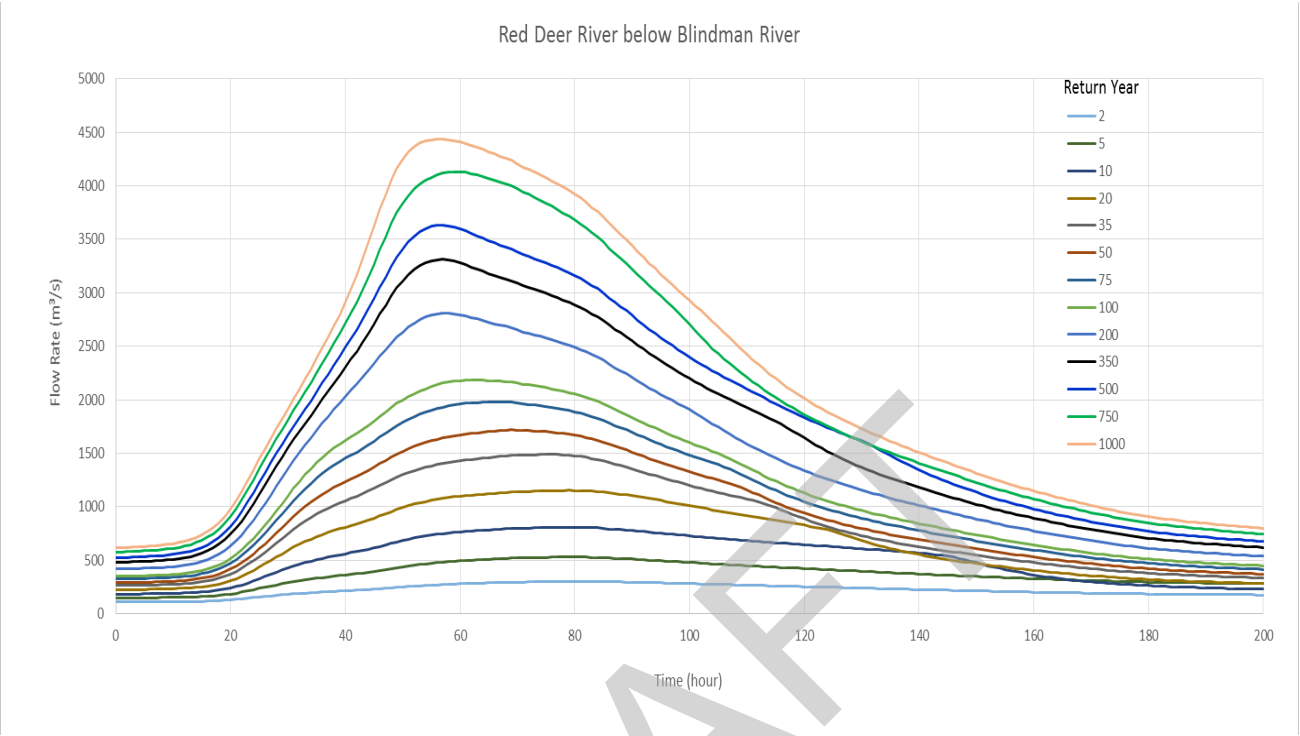


Figure C.3-8: Flood Hydrographs for Red Deer River below Blindman River

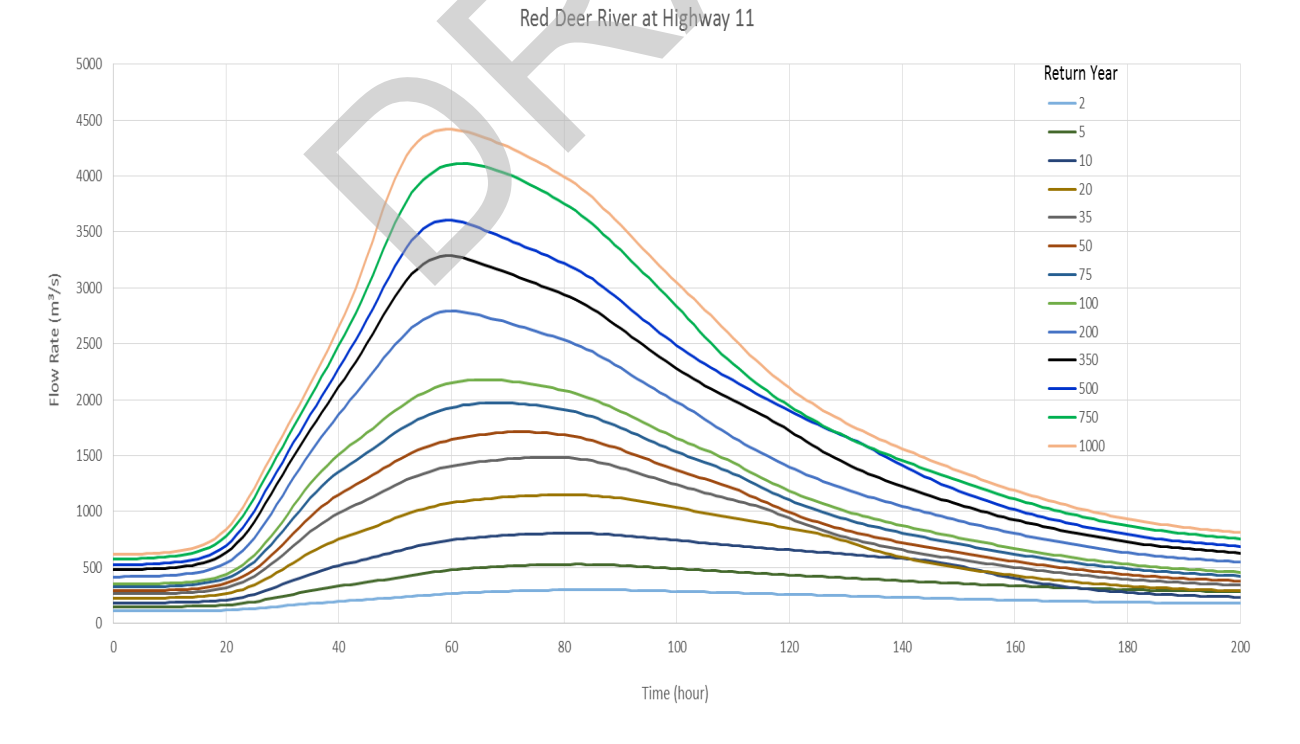


Figure C.3-9: Flood Hydrographs for Red Deer River at Highway 11

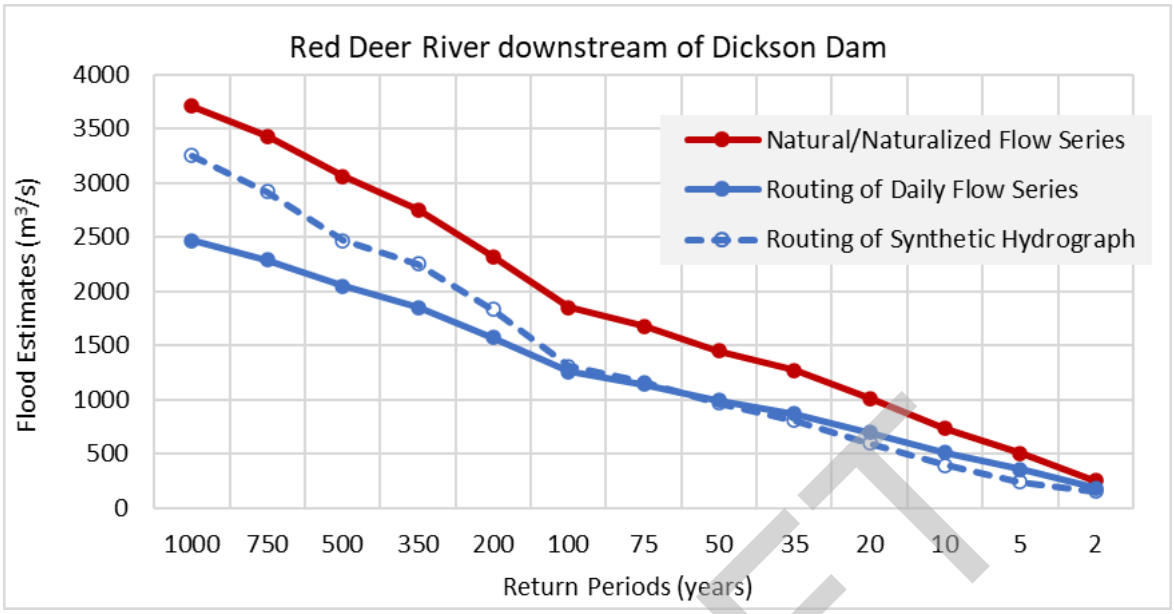


Figure C.3-10: Comparison of Flood Frequency Estimates using Three Methods at Red Deer River downstream of Dickson Dam.

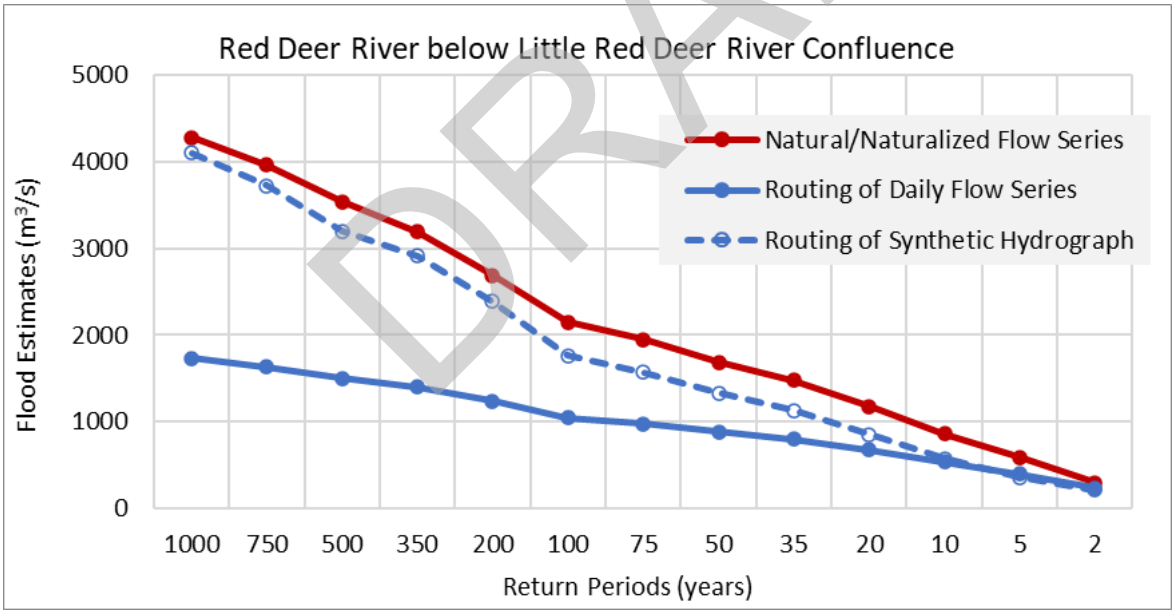


Figure C.3-11: Comparison of Flood Frequency Estimates using Three Methods at Red Deer River below Little Red Deer River Confluence.

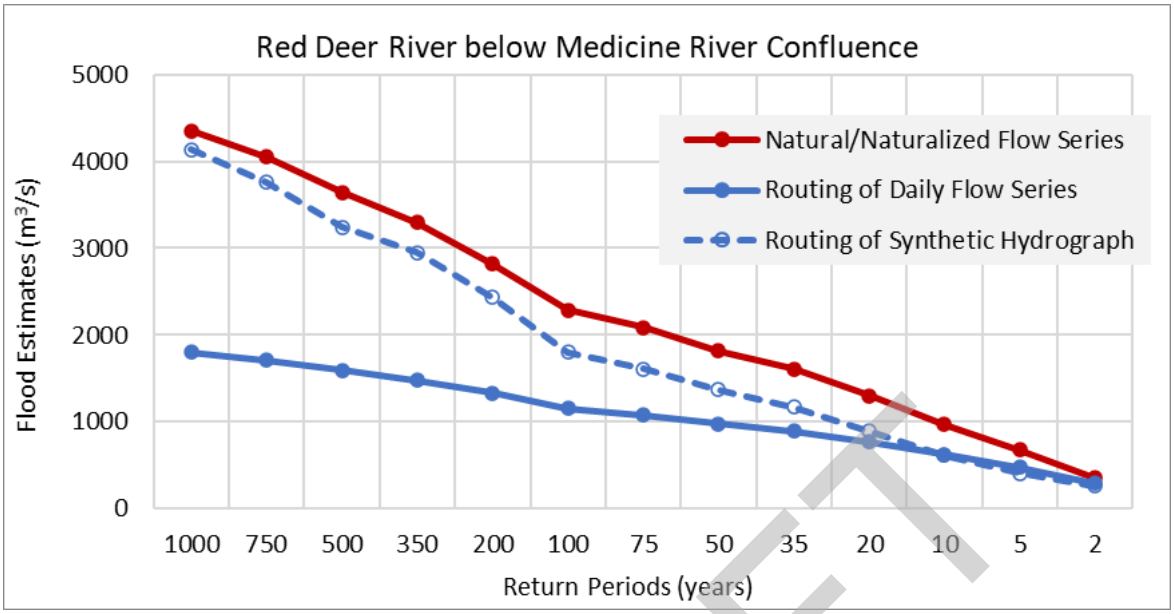


Figure C.3-12: Comparison of Flood Frequency Estimates using Three Methods at Red Deer River below Medicine River Confluence.

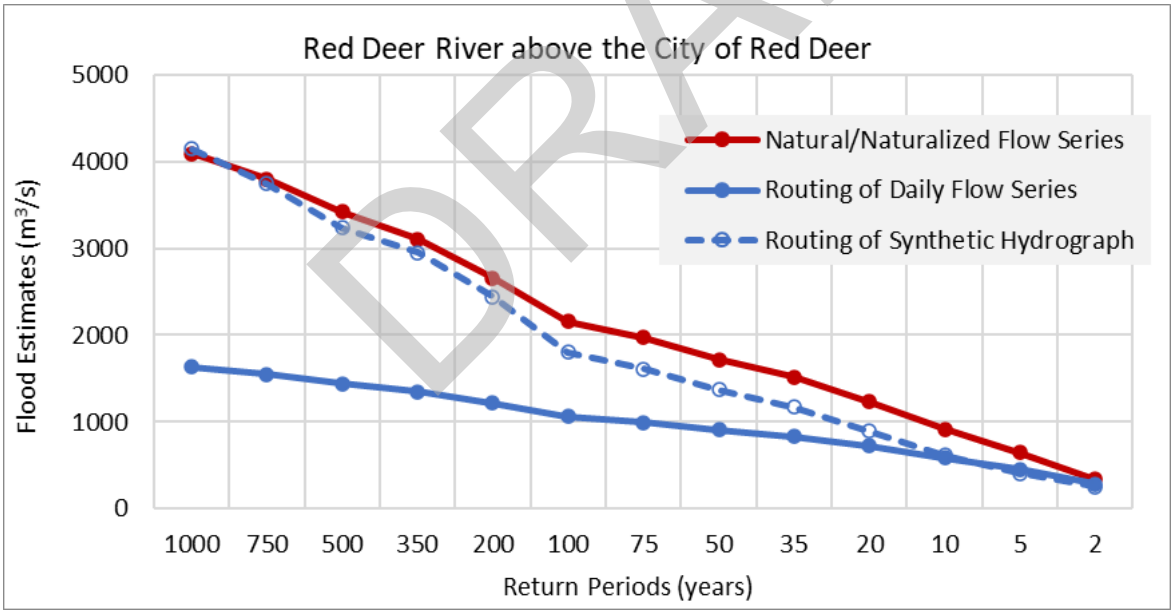


Figure C.3-13: Comparison of Flood Frequency Estimates using Three Methods at Red Deer River above City of Red Deer.

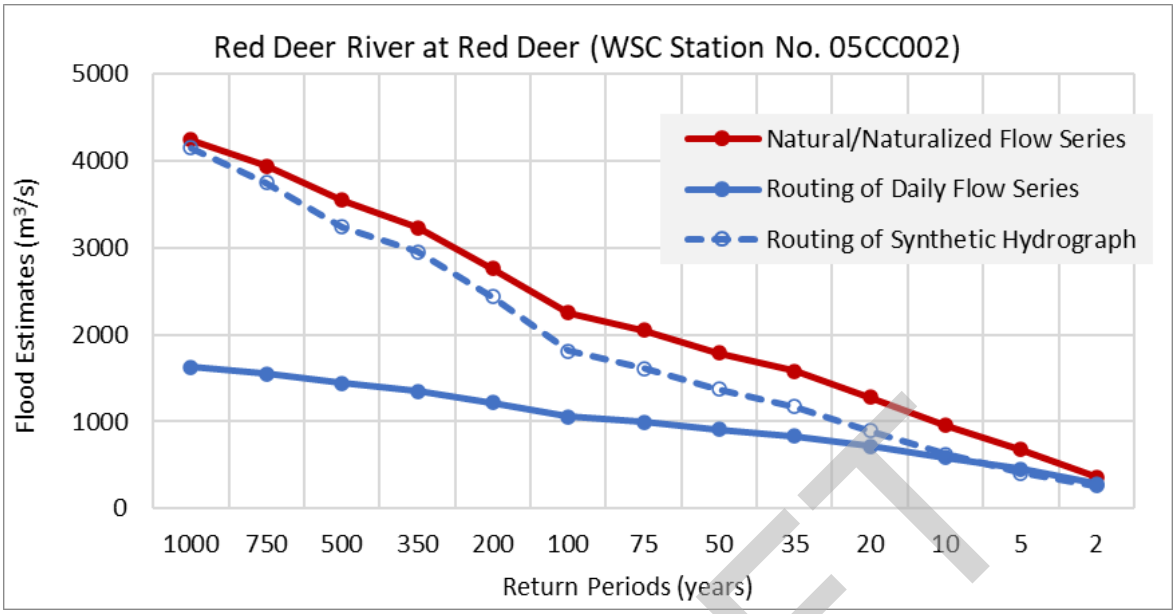


Figure C.3-14: Comparison of Flood Frequency Estimates using Three Methods at Red Deer at Red Deer (WSC Station No. 05CC002).

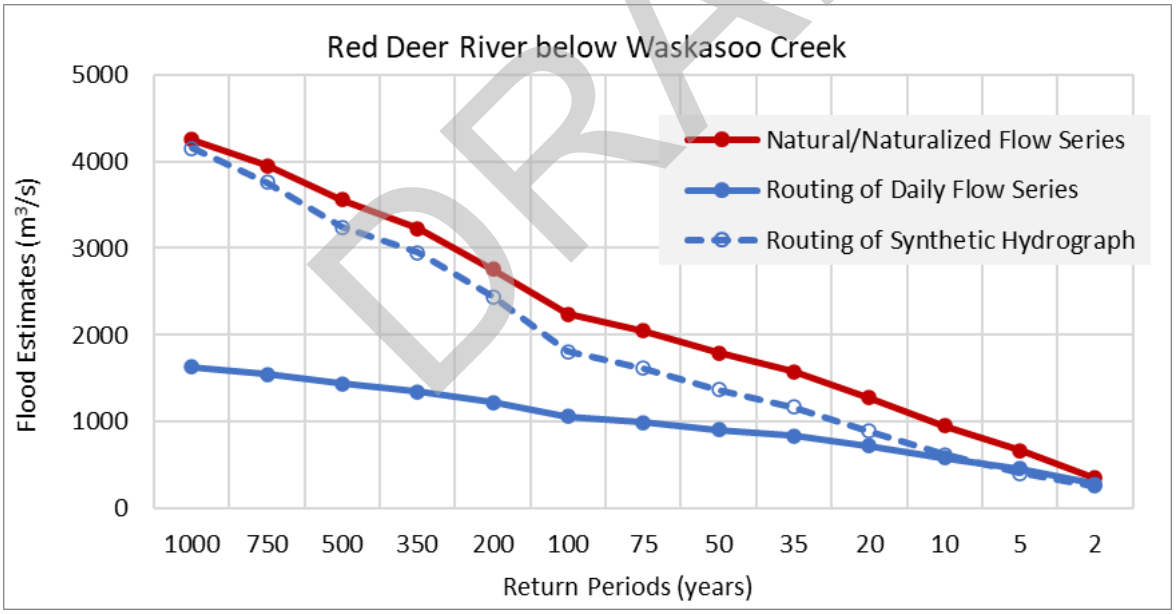


Figure C.3-15: Comparison of Flood Frequency Estimates using Three Methods at Red Deer River below Waskasoo Creek.

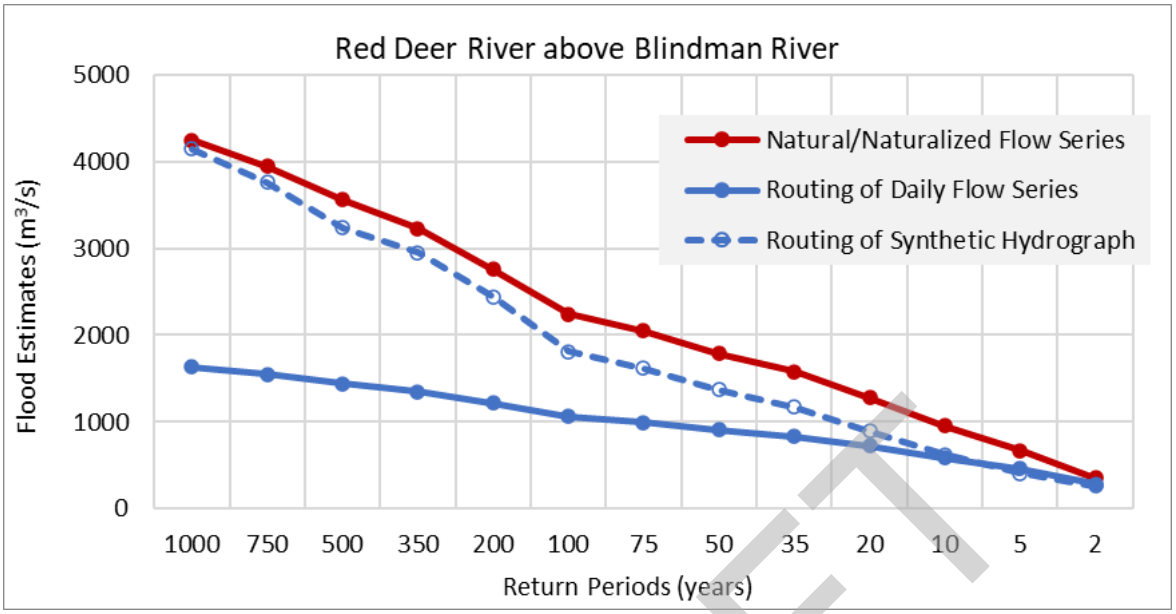


Figure C.3-16: Comparison of Flood Frequency Estimates using Three Methods at Red Deer River above Blindman River.

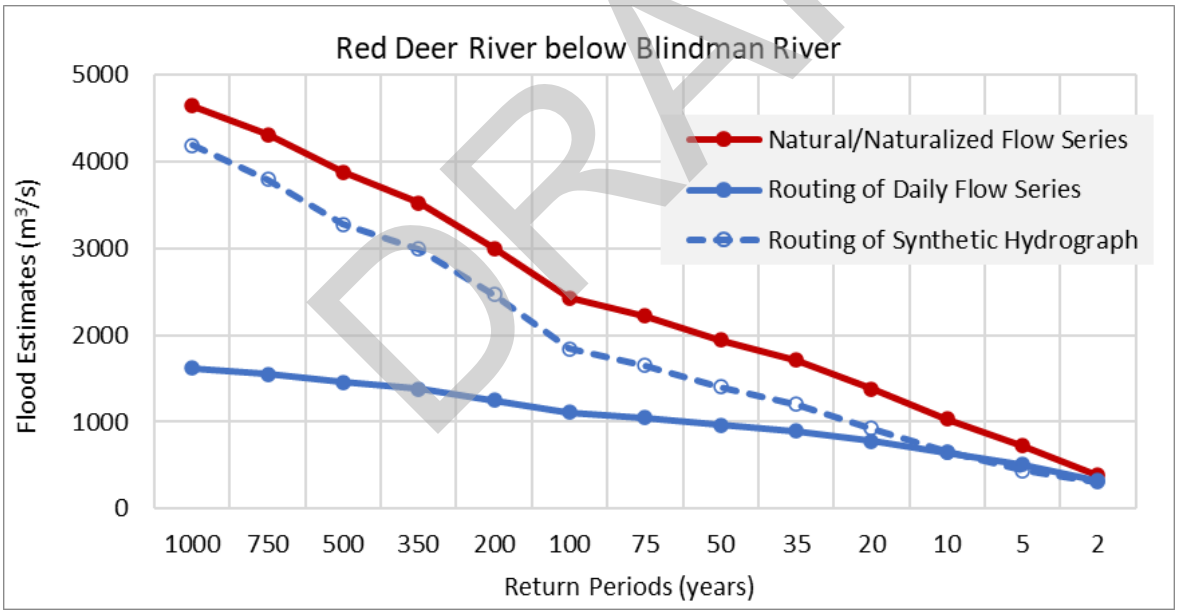


Figure C.3-17: Comparison of Flood Frequency Estimates using Three Methods at Red Deer River below Blindman River.

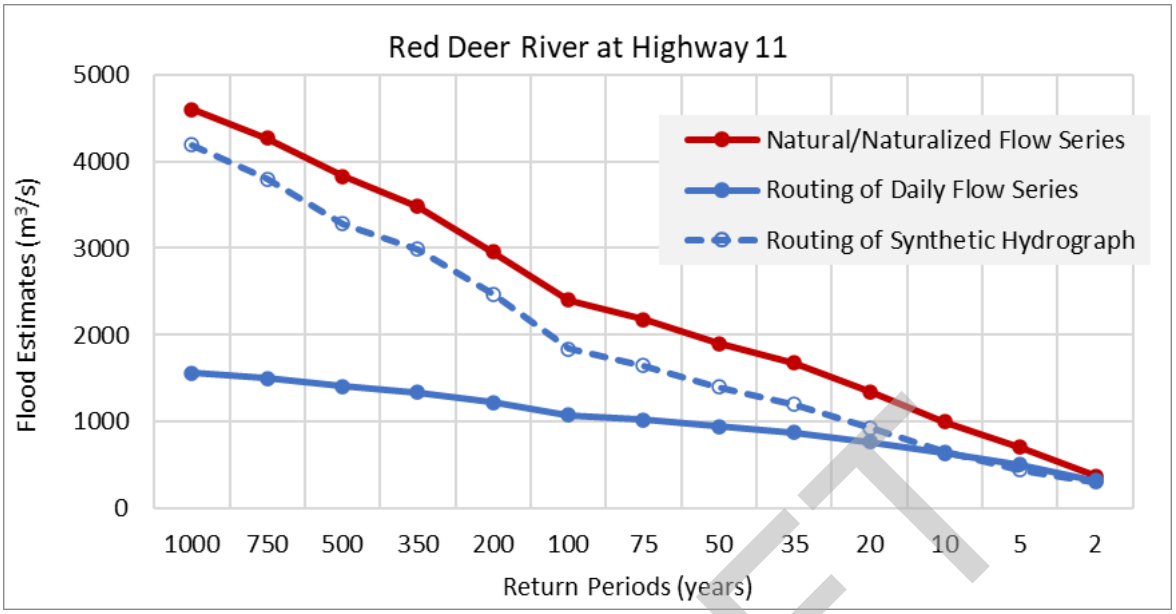


Figure C.3-18: Comparison of Flood Frequency Estimates using Three Methods at Red Deer River at Highway 11.

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